BISA Borlaug Institute for South Asia

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CIMMYT International Maize and Wheat Improvement Center

Manual on

Conservation Agriculture and Scale Appropriate Agricultural Mechanization in Smallholder Systems

CGIAR RESEARCH PROGRAM ON Climate Change, Agriculture and Food Security CCAFS

CORAF/WECARD

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Authors

Yadvinder-Singh, HS Sidhu, Manpreet Singh, HS Jat, RS Chhokar, R. Setia and ML Jat

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About Authors

Yadvinder-Singh is a soil scientist having four decades of research experience. He is working as a consultant with CIMMYT and BISA since past 7 years. Before, joining CIMMYT-BISA, he served PAU for more than 3 decades in various capacities. He is also an INSA Honorary Scientist.

HS Sidhu is a Principal Research Engineer at BISA, Ludhiana, India. He has over 28 years of experience on design, development, fine-tuning and scaling of scale appropriate conservation agriculture mechanization in the smallholder systems of South Asia.

Manpreet Singh is a Senior Research Engineer at Punjab Agricultural University (PAU), Ludhiana, India. He has made significant contributions for conservation agriculture mechanization in India.

HS Jat is a Principal Scientist (Agronomy) at ICAR-Central Soil Salinity Research Institute, Karnal, India. He also served CIMMYT for 5 years. He has done some pioneering work on Conservation Agriculture and Climate Smart Agriculture in Smallholder Systems.

RS Chhokar is Principal Scientist (Agronomy) at ICAR-Indian Institute of Wheat and Barley Research, Karnal, India. He is weed scientist of par excellence and during past 2 decades, he has contributed to development of weed management practices and strategies in irrigated intensive production systems of India.

R. Setia is a remote sensing scientist at Punjab Remote Sensing Center (PRSC), Ludhiana, India. He is working on geo-spatial analysis and adoption tracking of conservation agriculture in Punjab.

ML Jat is Principal Scientist/Systems Agronomist and Sustainable Intensification Strategy lead (Asia and North Africa) at Sustainable Intensification Program of CIMMYT. Over past 22 years, he has been working on design, development and scaling conservation agriculture based sustainable intensification and climate smart agriculture in smallholder systems of Asia and North Africa. He also led the capacity development program through advance courses on Conservation Agriculture for the young researchers and development practices of conservation agriculture in Asia and North Africa.

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Preface

The world is facing an unprecedented and continued degradation of agricultural soils, with negative impacts on food production. In developing countries, smallholder farmers are particularly susceptible to the consequences of soil and land degradation and the increasing variability and unpredictability of weather patterns caused by climate change. Expected increase in population will put increased pressure on the natural resources needed to produce enough food, projected and climate change makes the challenges greater. In recent years, conservation agriculture (CA) has received increased attention for productivity and sustainability of agriculture and food systems at the global level. Understanding and adoption of CA is one of the most important farming methods taking place in agriculture today. Both West African and South Asian countries are particularly vulnerable to climate change, high reliance on rain-fed agriculture, and limited economic and institutional capacity to respond to climate variability and change. Agriculture contributes about 30% of the global greenhouse gas emissions for climate change, which is already impacting the livelihoods of the most vulnerable, especially smallholder farmers. In recent years, productivity and sustainability of agriculture and food systems have received increased attention at the global level. Traditional cultivation methods used by the farmers cannot cope with the increasing needs of the ever-expanding human and livestock populations including the re-sequestration of atmospheric carbon. Thus, conservation actions to halt and reverse degradation as well as boost agricultural productivity have gained increasing interest in the recent past in South Asia and West Africa and the world at large. CA is considered as one of the best options to meet future food demands, prevent land degradation, minimize air pollution, and ensure sustainable agriculture and food security. If implemented well, CA will lead to efficient use of water, reduced use of agrochemicals, improved soil health, mitigation and adaptation to climate change, and increase in farmer income. CA as sustainable and resilient agricultural production systems is necessary to achieve the United Nations' Sustainable Development Goals (SDGs), which frame development agendas until 2030, include SDG1 (No Poverty), SDG2 (Zero Hunger) – the most important for improving the livelihoods of the rural poor and SDG12 (Responsible Consumption and Production) – important for protecting natural resources while producing sufficient nutritious food for the world's growing population. In essence, CA is an approach that advocates the concept of sustainable intensification of production by picking the best possible options that farmers can apply at their own conditions. Given the diversity of agricultural practices and cropping systems, adaptation and flexibility is vital in responding to the real needs of farmers and to challenges in the various agro-ecological zones. This manual is based on collective knowledge and experience of highly knowledgeable and experienced scientists, teachers, policy experts, and leaders from different organizations, including universities and public, private, and international institutions/ organizations. This manual includes the experience in the deployment of CA in South Asia which shares a dominance of small-holdings with Africa, albeit in a context of more developed infrastructure and better opportunities for technology adoption.

We emphasized that for many production environments the three principles of CA generally provide the best-bet approach, if widely adopted, to reach tangible goals of improving farm incomes while ensuring that soil health, water use efficiency and air quality and bio-diversity are protected. We do not suggest that every farm on the planet should convert to CA systems. In our opinion, it will be good for many agricultural production systems on global level.

Availability of trained human resources at ground level is one of the major limiting factors in adoption of CA. Training on CA should be supported at all levels. This warrants enhanced capacity of local stakeholders to deploy the principles of CA under their specific circumstances. However, weak capacities at institutional, community and various stakeholders' levels are hindrances to scaling-up CA in Africa and South Asia. Another limitation for its slow adoption is lack of knowledge on how to undertake CA research and harness its potential benefits. Special extension needs are required to scale up adoption of knowledge-intensive innovations such as CA, where timing of field operations is so critical. We hope that this training manual will be a valuable source of information for scientists, teachers, extension functionaries, students, progressive farmers and policy planners of India and West Africa. We thank all those who have contributed to the conceptualization, writing and production of the manual. Finally, it is our hope that in the coming years CA will bring increased food security and prosperity to many more households and communities in both India and West Africa.

Acknowledgements

This training manual on 'Conservation Agriculture and Scale of Appropriate Agricultural Mechanization in Smallholder Systems' is an outcome of several years of work and international training courses on Conservation Agriculture organized by CIMMYT and BISA in collaboration with Indian Council of Agricultural Research (ICAR), Punjab Agricultural University (PAU), Ludhiana and learnings from conservation agriculture research undertaken over a decade under the aegis of CGIAR Research Programs (CRPs) on Climate Change, Agriculture and Food Security (CCAFS), Wheat Agri-Food Systems (WHEAT), Cereal Systems Initiative for South Asia (CSISA), ICAR-Conservation Agriculture (ICAR-CA). In addition, the special international training courses organized during 2018 and 2019 at BISA, Ludhiana under the aegis of CORAF/WECARD and funded by the World Bank, have contributed to this manual. The resource persons in the area of agronomy, soil science, social sciences and agricultural engineering, plant breeding, environmental sciences involved in the training courses, had vast experience and knowledge in developing and promoting CA practices through their institutions. We greatly appreciate their contributions in bringing this manual to this present state. There are numerous valuable articles, case studies, discussion papers, and documents that have been referred to, throughout this manual compilation. We would like to sincerely acknowledge the financial support from ICAR-DARE, CCAFS, WHEAT, CORAF/WECARD (World Bank) for relevant research and development of this training manual. We would like to express our sincere gratitude to all those who provided support, read, wrote, offered comments, and assisted in the editing, management, and proof-reading of this manual. Our sincere thanks to Senior management of CIMMYT, BISA and ICAR for their continued support and motivation. Last, but not least, we thank all those who have directly or indirectly contributed to this effort.

Authors

About the Training Manual

This manual has focused on the need to amplify and accelerate adoption of conservation agriculture (CA) practices that enable productivity increases on a sustainable basis. The development of the training manual on 'Conservation Agriculture and Scale Appropriate Agricultural Mechanization in Smallholder Systems' is an outcome of the series of advanced training programs on Conservation Agriculture over past one decade. The objectives of this training manual are; (1) To foster capacity building of researchers, extension workers, farmers and machinery manufacturers to promote CA in Asia and Africa; and (2) To raise the awareness of policy planners and decision makers to develop a strategic plan for the development of CA and agricultural mechanization in the developing world. There are several initiatives in South Asia and Africa to promote CA practices as environment-friendly and alternative to conventional agriculture. However, little has been done to document the CA practices or even lessons learnt from these initiatives. Farmers today still lack access to information on CA practices. This is a comprehensive manual that explains in a step by step easy to follow manner on how to implement CA by smallholders in Asia and Africa. It explains what CA is, and why it is important, how to use CA principles in the field and highlights the issues and challenges that researchers, farmers, machinery manufacturers and service providers may encounter when they adopt and adapt CA practices. This manual aims to be a valuable reference and is intended for use by researchers, agricultural extension officers/workers, farmers, machinery manufacturers and service providers to promote CA in Asia and Africa for increasing productivity and reducing poverty. It is written in clear, easy-to-understand language, and is illustrated with numerous figures and tables. It is not intended to cover the subject of conservation agriculture comprehensively but to provide an overview of the principles and practices. Indeed, as the training draws from many distinct disciplines, it is unlikely that any one person will have the necessary technical skills to cover the complete course content. Manual also focuses on two crucial aspects: the provision of farm mechanization services as a viable business opportunity for entrepreneurs, and the essential criteria of raising productivity in an environmentally sensitive and responsible way. This manual is also designed to serve as source of information for custom hire service providers – whether already in the business or intending to start their own hire service business – with skills and competencies in both the technical and the management aspects of the small-scale mechanization business. CA to reach smallholder farmers needed the publication of simplified technical manual. This manual contains useful technical information on CA practices that offer practical answers to questions normally asked by farmers of what, why, how.

The training manual covers a range of topics and the contents of the manual have been divided into 9 chapters. **Chapter 1** presents the challenges of traditional agriculture, and importance, definitions and principles and clarifies terminologies related to CA. This chapter aims at increasing understanding of factors, issues, and challenges that impact on the productivity and sustainability of the agriculture and food systems now and will continue to do so into the 21st century. It also highlights potential benefits associated with CA and provides options for farmers intending to practice CA. In this chapter we discussed the history of CA adoption and how CA adoption is one of the major tools for sustainable intensification of crop production, contributing to strategic goals such as climate-smart agriculture, poverty reduction and food security. **Chapter 2** clarifies what is meant by the term "agricultural mechanization and its importance to be viewed in a much broader context. It provides need why a strategic approach is vital for the development of agricultural mechanization in CA. **Chapter 3** presents an overview of the scale appropriate value chain mechanization for CA. Successful adoption of CA will call for accelerated effort in developing, standardizing and promoting quality machinery aimed at a range of crops and cropping sequences suited to local conditions.

This chapter provides useful information on the calibration of different machinery and equipment used in CA. **Chapter 4** describes principles and practices for different CA based practices. Whole range of practices in CA, including planting and harvesting, water and nutrient management, diseases and pest control have been discussed in this chapter. **Chapter 5** describes the importance of CA in improving soil health (chemical, physical and chemical) for sustainable food production. **Chapter 6** discusses the role of conservation agriculture in mitigating and adapting to the adverse effects of climate change on agriculture. **Chapter 7** describes the aapplication of remote sensing, geographical information system and Internet of Things in precision agriculture. **Chapter 8** discusses steps needed for upscaling CA and agriculture mechanization in smallholder systems. It gives an account of constraints and challenges found in the adoption of CA practices. This chapter also provides recommendations on policy support for scaling CA and agricultural mechanization. It also focuses on research and innovation, policies and incentives, resource mobilization, and governance and institutions—the four areas considered most critical to the upscaling of CA. **Chapter 9** ends with conclusions and way forward. It provides a set of recommendations that, if adapted and adopted at national, and local levels, CA would improve productivity and sustainability of agriculture and food systems. We hope that this training manual will be a valuable source of information for scientists, teachers, extension functionaries, students, progressive farmers and policy planners of both India and West Africa. This manual is the effort to point the pathway toward CA for more sustainable agriculture and food systems through an integrated and cross-sectoral approach.

Content

Acronyms and Abbreviations

AE	Agronomic efficiency
APA	Alkaline phosphatase activity
BD	Bulk density
BISA	Borlaug Institute for South Asia
CA	Conservation agriculture
CCAFS	Climate change Agriculture and Food Security
CDA	Controlled droplet application
CEC	Cation exchange capacity
CHC	Custom hiring centre
CH4	Methane
CIMMYT	International Maize and Wheat Improvement Center
CO	Carbon monoxide
COARF	Commission on Accreditation of Rehabilitation Facilities
CO2	Carbon dioxide
COP	Conference of the Parties (COP) to the United Nations
CSA	Climate smart agriculture
CT	Conventional tillage
DHA	Dehydrogenase activity
DNA	Deoxyribonucleic acid
DSR	Direct seeded rice
EC	Electrical conductivity
EIGP	Eastern Indo-Gangetic Plain
ET	Evapotranspiration
FAO	Food and Agriculture Organization
FUE	Fertilizer use efficiency
GHG	Greenhouse gas
GIS	Geographical Information System
GS	GreenSeeker®
GWP	Global warming potential
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IGP	Indo-Gangetic Plain
INSEY	In season estimation of yield
IoT	Internet of Things
IPM	Integrated pest management
IPNI	International Plant Nutrition Institute
KVKs	Krishi Vigyan Kendras
LCC	Leaf colour chart
MBC	Microbial biomass carbon
MPN	Most probable number
N	Nitrogen
NDVI	Normalized Difference Vegetation Index
NE	Nutrient Expert®
N_2O	Nitrous oxide
NGOs	Non-Governmental Organizations
NOx	Nitrogen oxides
NUE	Nitrogen use efficiency
NW	North-West
PACS	Primary Agricultural Cooperative Societies
PAU	Punjab Agricultural University
PLFA	Phospholipid fatty acids
PRB	Permanent raised bed
PTO	Power turn off
RCTs	Resource conservation technologies
RE	Recovery efficiency
RNA	Ribonucleic acid
RWS	Rice-wheat system
SA	South Asia
SDGs	Sustainable Development Goals
SMB	Soil microbial biomass
SMP	Soil matric potential
SO_2	Sulphur dioxide
SOM	Soil organic matter
SOC	Soil organic carbon
SPAD	Soil Plant Analysis Division
SSA	Sub Saharan Africa
SSNM	Site-specific nutrient management
STD	Strip till drill
VAM	Vesicular-arbuscular mycorrhiza
2-WT	Two-wheel tractor
4-WT	Four-wheel tractor
WECARD	West & Central African Council for Agricultural Research & Development
WP	Water productivity
ZT	Zero-till

1 Agricultural Challenges and Conservation Agriculture

1.1 Introduction

The agriculture in Africa as well as South Asia faces a double challenge: to increase production to meet the food demand of growing human population with a lower environmental footprint and preserve natural resources simultaneously. At the same time, per capita availability of land and water are significantly declining. Moreover, the climate change and water scarcity has made the agricultural production systems highly vulnerable impacting the lives and livelihoods of millions of people in this part of the world. Agriculture is responsible for about 30% of the total greenhouse gas (GHG) emissions of CO_2, N_2O and CH_4 while being directly affected by the consequences of a changing climate. The conventional intensive agriculture practices were successful in achieving goals of production, but simultaneously led to degradation of natural resources endangering agricultural productive potential in the future. This form of agriculture has been accused of being responsible for soil organic matter decline, soil structural degradation, reduced water infiltration rates, soil erosion problems, inefficient water use and contribution to global warming problems. These challenges draw attention to the need and urgency to address options by which threats to West African and Indian agriculture due to natural resource degradation, escalating production costs and climate change can be met successfully. Conservation agriculture (CA) was introduced by the FAO in 2008 as a concept of resource-efficient agricultural crop production system in meeting the challenges faced by the agriculture today. CA has been proposed to reverse degradation of natural resources in an effort to move towards sustainable cropping systems. Sustainability is a concern in today's agriculture and CA constitutes a sound approach for moving in this direction. Converting from conventional practices to CA will help in sustaining soil health by improving soil organic carbon (SOC), aggregation, infiltration and reducing erosion losses. CA practices hold the promise of providing both a strategy for mitigating climate change and also working as an adaptive mechanism to cope with climate change. CA holds special promise for Africa to increase crop productivity, where farming communities face the problems of low yields, poor soil health, lack of capital, and labour shortages. It is compatible with a wide range of agriculture production systems and farm types. However, CA practices need to be modified to make them work by a strategy of identifying site-specific components.

The various practices that make up this approach follow key principles based on the conservation of soil, water, nutrients and farm power. CA is a promising approach that advocates the concept of sustainable intensification of agricultural production by picking the best possible options that farmers can apply at their own conditions. In CA, appropriate type of farm power and farm equipment and machinery have a significant influence on intensification and optimization outcomes, and on profit. CA techniques can be adopted by farmers with resources such as animals and implements as well as by those farmers who have no draught power or equipment. It is regarded as more water-, nutrient-, energy- and labor-use-efficient. It can help mitigate and adapt production to climate variability as a result of more efficient and productive use of water resources. Over the past 3 decades globally, CA has emerged as a way for transition to the sustainability of intensive production systems.

1.1.1 Problems and challenges with Conventional Agriculture

In conventional agriculture, intensive tillage loosens the soil, control weeds, improves the release of soil nutrients for crop growth, and modifies the water movement and air within the soil. However, intensive tillage has been found to cause gradual decline in soil organic carbon (SOC) through accelerated oxidation and erosion resulting from excessive break down of soil aggregates. Currently, conventional tillage (CT) methods are a major cause of soil loss by erosion, accelerated by wind and water and desertification in many developing countries including Africa. Furthermore, in conventional agriculture, removal or burning of crop residues causes pollution through GHG emission and loss of valuable plant nutrients and inadequate crop rotations have contributed to a worsening situation in many countries. The frequent use of heavy machinery for tillage releases GHG to environment and compacts the soil. Under smallholder agriculture in West Africa, CT for farmers with access to draught animal power is characterized by the use of the animal-drawn mouldboard plough for primary tillage followed by harrowing and cultivation during the cropping season for weed control. For smallholder farmers without access to draught animal power, CT is still based on hand hoe cultivation in sub-Saharan Africa. Conventional agriculture cannot cope with the increasing needs of the ever-expanding human and livestock populations. In the conventional systems, while soil tillage is a necessary requirement to produce a crop, tillage does not form a part of this strategy in CA. In the conventional system involving intensive tillage, there is a gradual decline in soil organic matter through accelerated oxidation and burning of crop residues causing pollution, GHGs emission and loss of valuable plant nutrients. When the crop residues are retained on soil surface in combination with no tillage (NT), it initiates processes that lead to improved soil quality and overall resource enhancement. Globally, it took few decades for the farming community to shift away from the common belief that intensive ploughing was the only way to improve farm productivity to a belief that drastically reduced or zero tillage (ZT) was more advantageous. For ensuring food and nutritional security in one hand and conserving natural resources and ensuring environmental security, on the other hand; there is urgent need to employ and adopt CA based best practices in various aspects of agriculture. CA is a sustainable management system for both irrigated and rainfed areas.

Rather than presenting a strict set of rules, CA provides guidelines for growing crops in a more sustainable way, which allow farmers to adapt CA practices to local and regional conditions, such as soil type, rainfall patterns, and financial resources. When the crop residues are retained on soil surface in combination with ZT, it initiates processes that lead to improved soil quality and overall resource enhancement. CA systems require a total paradigm shift from conventional agriculture with regard to management of crops, soil, water, nutrients, weeds, and farm machinery (Table 1.1). CA represents a fundamental change in the soil system management and in the cropping system design and management which in turn lead to consequential changes in the required field operations and the related mechanization solutions.

Table 1.1. Some distinguishing features of conventional and conservation agriculture systems

Sr No.	Conventional agriculture	Conservation agriculture
1	Cultivating land, using science and technology to dominate nature	Least interference with natural processes
2	Excessive mechanical tillage and soil erosion	No-till or drastically reduced tillage
3	High wind and soil erosion due to reduced vegetation cover and pulverization surface layer	Low wind and soil erosion
4	Residue burning or removal (bare surface)	Surface retention of residues (permanently covered)
5	Water infiltration is low causing runoff and soil erosion and inefficient use of fertilizers leading to pollution.	Infiltration rate of water is high
6	Use of ex-situ FYM/composts	Use of in-situ crop residues and cover crops
7	Kills established weeds but also stimulates more weed seeds to germinate	Weeds are a problem in the early stages of adoption but decrease over time

Sr No.	Conventional agriculture	Conservation agriculture
8	Free-wheeling of farm machinery, increased soil compaction in crop area. Poor root development and low yields and less profit	Controlled traffic, compaction in tramline, no compaction
9	Mono cropping/culture, less efficient rotations	Diversified and more efficient rotations
10	Heavy reliance on manual labor, uncertainty of operations	Mechanized operations, ensure timeliness of operations
11	Poor adaptation to stresses, yield losses greater under stress conditions	More resilience to stresses, yield losses are less under stress conditions
12	Productivity gains in long-run are in declining order	Productivity gains in long-run are in incremental order

1.2 Definition and Objectives of Conservation Agriculture

Conservation agriculture means ways of farming that conserve natural resources of soil and water resulting in improved and sustainable production. The term 'conservation agriculture' was adopted during the First World Congress on CA that was organized in 2001 by the FAO and the European Conservation Agriculture Federation in Spain. CA is defined by FAO (http://www.fao.org.ag/ca) as "a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment". The term CA refers to the system of raising crops without tilling the soil while retaining crop residues on the soil surface. Land preparation through precision land levelling and bed and furrow configuration for planting crops further enables improved resource management. CA permits management of soils for agricultural production without excessively disturbing the soil, while protecting it from the processes that contribute to degradation e.g. erosion, compaction, aggregate breakdown, loss in organic matter, leaching of nutrients etc. It is a way to achieve goals of enhanced productivity and profitability while protecting natural resources and environment, an example of a win-win situation. CA has emerged as a new paradigm to achieve goals of sustainable agricultural production in South Asia (Jat et al., 2011). CA is not "business as usual", based on maximizing yields while exploiting the soil and agro-ecosystem resources. Rather, CA is based on optimizing yields and profits, to achieve a balance of agricultural, economic and environmental benefits. CA refers to the system of raising crops without tilling the soil while retaining crop residues on the soil surface. The objectives of CA are to achieve i) acceptable profits, ii) high and sustained production levels, and iii) conserve the environment making judicious use of natural resources (soil, water and air). CA is a sustainable approach that prevents soil degradation and controls erosion. It is a sustainable agricultural production system that includes a set of agronomic practices adapted to the demands of the crop and the local conditions of each region, whose techniques of cultivation and soil management protect it from erosion and degradation, improve its quality and biodiversity, contribute to the preservation of natural resources such as water and air, without impairing the production levels of the farms. CA provides windows of opportunity for sustainable intensification through high system productivity, profits and resource (water, nutrient) use efficiency, ensuring human nutrition through short duration pulses and system sustainability and soil resilience.

1.3 Principles of Conservation Agriculture

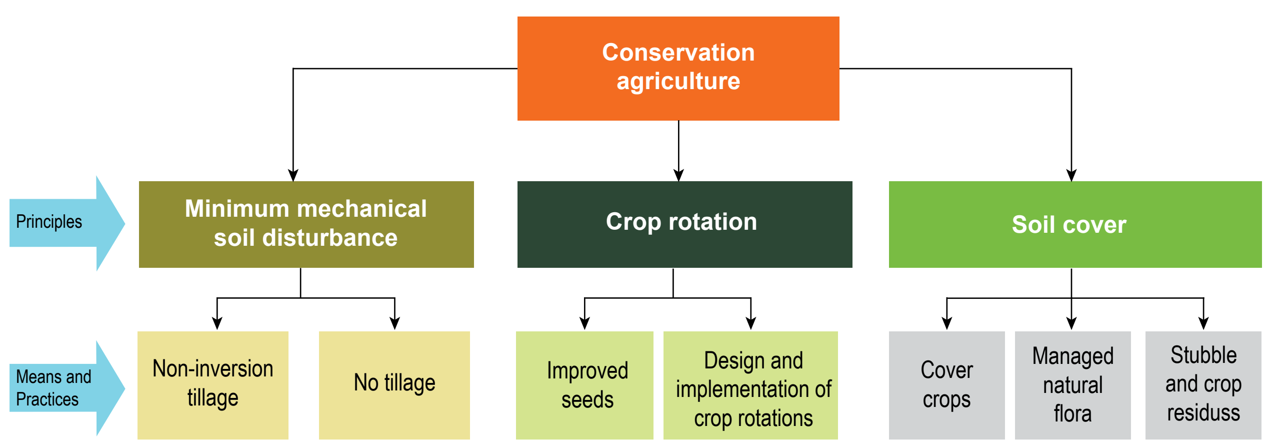
CA relies on the simultaneous application of three core principles (also called as three pillars) which are linked to each other in a mutually reinforcing manner: 1) Minimum soil disturbance or no tillage; 2) Permanent organic soil cover through crop residues or other cover crops, permanent or at least during critical stages, not burning crop residue, and controlling grazing; and 3) Diversification of crop species through the use of crop rotations or/and intercropping (Fig. 1.1) (FAO, 2012). The three interlinked principles must be considered together for appropriate design, planning and implementation processes. Adoption of complete package of practices in CA has more benefits than the discrete adoption of its components, hence there is a need for advocacy on the unification of these components. In addition to three basic principles, CA principles should be complemented by other good farming practices (e.g. use of quality seed, balanced and precision nutrient management, integrated management of pests, diseases and weeds, efficient water management, etc.) for further improvement in the overall performance and resilience of the cropping system. While CA principles are universal, their application to local situations is site-specific. Therefore, local experimentation and adaptation – by farmers for farmers – is an essential ingredient to scaling out CA. By applying the three CA principles, farmers can improve soil health and grow more food, using less labour, and at lower cost. CA principles can be integrated into most rainfed and irrigated production systems to strengthen their ecological sustainability. The application of CA implies a change in the management of the soils, since tillage is not used to prepare the seedbed. Therefore, it is necessary to use seeding machines adapted to work on soils with a compact seedbed and groundcovers, and to control weeds with herbicides instead of ploughing.

Recently, fertilizer application has been proposed as a separate principle in addition to good agronomic practices as fertilizer is essential for CA to exhibit its fullest potential, while the suboptimal implementation of other crop management practices might not lead to the success of CA as such particularly in the African countries. Harford and Breton (2009) suggested three more principles of CA; (i) Timely implementation: carrying out all operations at the best time of the year (preparing land such as basin and ripping before the rain starts, planting, fertilisation, controlling weeds and pests); (ii) Precise operations (paying attention to detail and doing all tasks carefully and completely); and (3) Efficient use of inputs (including labour, time, seeds, crop residue, fertilizer, water). In CA, better responses to N application are realised with basins even during drought years. Usually with farmer practice, good returns with N application are only evident in average to above average rainfall season. This gives higher yields and huge savings on costly inputs. The three key principles of CA are discussed in detail as under:

i. Minimum/zero tillage:

First key principle is to only disturb the soil where the seed and fertilizers are to be placed. Minimum soil disturbance has numerous benefits, and overcomes many of the disadvantages of ploughing. The damaging effect of intensive tillage led to the promotion of minimum tillage which encompasses management practices that reduce tillage intensity either through the exclusion of at least one major cultivation practice or minimising the depth of tillage operations. Conservation tillage is developed from reduced tillage and aims at maintaining a soil cover of at least 30% after planting so as to minimize wind and water erosion, and maximise soil and water

Figure 1.1. The three principles of conservation agriculture and the main practices and means needed to achieve each principle.



conservation. If we disturb the soil by ploughing or turning the soil, we damage the structure of the soil, which makes it harder for rainwater to infiltrate into the soil, as natural drainage pathways are disrupted. It also makes the soil susceptible to erosion. Tillage destroys organic matter in the soil. Soil organic matter is acted upon by microorganisms to form humus – a stable compound which stores nutrients and water in the soil. Soils with poor organic matter content are less capable of storing nutrients and become less fertile. Soils with high organic matter content can store nutrients and water for longer. Minimum soil disturbance reduces organic matter oxidation and so organic matter build-up occurs, reduces destruction of the soil structure and improves soil aggregation, increases infiltration rate, does not expose soil to wind and water erosion, causes little disruption to the soil organisms, reduces soil compaction, and saves time, energy, and money because less land is tilled.

Minimum tillage in CA can be achieved through manual, animal- and tractor based seeding equipment. Zero till planters have been designed in a way that causes minimal disturbance to the soil and previous crop residues while placing the seeds in an optimum position for germination and emergence. For farmers in West Africa with limited access to mechanical power, animal-traction based CA uses ripper tines, chisel and coulters whereas in more mechanised holdings tractor-drawn no-till planters are used. These can be in the form of single or double furrow openers, single disc coulters and no-till direct seeders. Timely planting of crops under ZT systems in both irrigated and rainfed ecologies helps the crop to escape negative effects of terminal water stress and rising temperatures.

ii. Permanent soil cover

It is a fundamental principle of CA and is probably the biggest difference from conventional practice. Permanent crop cover with residue of previous crop, raising cover crop, dry grass and leaves, and other dead plant material on the field is a pre-requisite and an integral part of CA, in order to offer a natural increase of organic matter content in surface horizons.

In the past agriculturists encouraged 'clean' fields – free of crop residues or other organic materials. They thought that organic materials caused poor germination, contained pests and diseases and interfered with operations like planting and weeding. Traditionally crop residues are burned or removed after harvesting or animals allowed to freely graze in the fields. The field burning of crop residues is a major contributor to reduced air quality (particulates), human respiratory ailments, and the death of beneficial soil fauna and micro-organisms. During burning of crop residues around 80% of carbon is lost as CO_2 and a small fraction is evolved as CO. Apart from loss of carbon, >80% loss of N and S occurs during burning of crop residues.

The extent of soil cover will depend on the amount of the crop residue production and its removal for other purposes such as animal fodder. Smallholder farmers are recommended to retain any available crop residue as surface mulch in CA. In smallholder areas in semi-arid Africa, the problem is of limited availability of crop residue mulch. Plant biomass production is low under smallholder agriculture and whatever crop residue is available is grazed in situ by free ranging livestock during the long winter period. Consequently, the adoption of crop residue is low under these farming systems. A cover crop is grown to provide soil cover either in pure stand or in association with the main crop during all or part of the year. Cover crops also provide additional fodder for livestock in mixed crop/livestock systems, A permanent soil cover (mulch), serves a number of beneficial functions, including reduction of raindrop impact and so protects the soil surface from erosion, increasing infiltration and reducing run-off rate, decreasing surface evaporation losses and so conserves moisture for the crop, moderating soil temperature, suppressing weed emergence, provides the micro and macro organisms in the soil with a constant supply of food, and in the long term, the organic residues improve organic matter content and soil nutrient status. However, there are challenges to promoting the use of crop residues for mulching when farmers convert from conventional approaches to conservation agriculture. Farmers experience difficulties in planting into a thick layer of crop residue mulch. New variants of zero-till seed-cum-fertilizer drill/planters such as Happy Seeder (Sidhu et al., 2015) have since been developed to facilitate direct drilling of seeds in the presence of heavy loads of surface retained residues (both loose and anchored residues).

iii. Crop diversification/rotation

Crop diversification as the third principle of CA, is useful in providing higher protection against risk associated with climate change in addition to assured net returns to the farmers. Consequently, crop rotation is an important management tool in CA and is reported to contribute to the long-term sustainability of agricultural systems. Risk reduction through crop diversification related to abiotic and biotic stresses particularly in fragile ecosystems will contribute to improved food security and income generation for resource-poor farmers while protecting the environment. CA encourages profitable and agronomically efficient rotations: usually cereal and legumes or cash crops. A well–planned rotation that meets multiple objectives is recommended in CA. In semi-arid areas, drought tolerant crops such as sorghum (*Sorghum bicolor* L.), pearl millet (*Pennisetum glaucum*.) and cowpeas are recommended under CA. Study conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad revealed that maize/pigeon pea intercropping system is more sustainable and associated with less risk compared to maize - chickpea sequential cropping system and surface runoff was 28% less as compared to the conventional system, which may be attributed to residues retention. Rotation sequences that include crops with different lifecycles, planting and harvesting dates, rooting depth and growth habit diversify the cropping system and may result in the greatest benefits. CA encourages profitable and agronomically efficient rotations: usually cereal and legumes or cash crops. Taken together, these practices have the following advantages:

Better control of weeds, diseases and pests by breaking their life cycles; reducing the risk of total crop failure in cases of drought and disease outbreaks.

i. Crop rotations involving legumes helps in biological nitrogen fixation and improvement in N availability in soil and enhancing biodiversity.

ii. Intercropping different crops with different feeding zones which do not compete for nutrients enabling crops to use the nutrients in the soil more effectively.

iii. Nutrient losses are minimized by the use of deep rooting cover crops that recycle nutrients leached from the topsoil. enabling crops to mobilize the deeper nutrients in the soil more effectively.

iv. By selecting suitable rotations, the periods of high labour demand can be reduced and farming operations can be better distributed throughout the year. For example, sowing and harvesting dates for the different crops involved in the rotation do not coincide in time.

v. Reduce the risk created by extreme weather events such as droughts or floods and their negative effects, since their incidence does not equally affect all crops.

vi. Can balance the production of crop residues by alternating crops that produce few and/ or easily degradable residues with crops that produce many and/ or more long-lasting residues.

However, farmers in many African countries rarely practice crop rotation for a number of reasons. Shortages of legume seed restrict planting. Legumes are normally grown for local consumption only, so if production is increased then additional output markets will be needed in which to sell the surplus. Farmers often give priority to growing cereal crops because cover crops compete for moisture. This last reason is a problem that conservation agriculture helps to overcome and thus helps intercropping to become a viable option.

1.4 Conservation Agriculture in Rainfed Agroecosystems

Adoption of CA in rainfed farming is an emerging dimension for recycling crop residues into soil system and improving SOC stock in the surface layer. In arid (< 500-mm rainfall) region, low tillage is comparable to CT and weed problem is manageable. In semiarid region (500–1000 mm), CT can be superior to reduced tillage, and successful crop production depends on water infiltration and conserving soil moisture in the profile. Weed infestation is an transient problem depending upon the seasonal rainfall distribution in subhumid (~ 1000 mm of rainfall per year) regions, but there is a possibility of reducing the intensity of CT by using herbicides. CA system can help in improving yields in rainfed farming on Alfisols. These soils are shallow, with compacted subsoil horizon, and are also susceptible to hard setting. To harness advantages of CA systems in semiarid tropics, it is essential to retain crop residues on the surface as mulch, which is a major challenge in India due to competing demands as fodder for livestock and other uses. But the potential for CA exists in rainfed crops like maize, pigeon pea, castor, cotton, sunflower, etc., where CRs are not used as feed and for other competing purposes. Soils cultivated for rainfed farming are prone to numerous constraints (e.g., surface sealing, cracking, and hard setting). Ensuring good seed germination and crop stand establishment are major challenges to be addressed with CA and CR management. Being the only source of water, interactions between rainwater conservation and CA must be studied in an integrated manner. With canopy cover of maize grown during the rainy season, there is a possibility of growing a postrainy legume (i.e., horse gram, *Macrotyloma uniflorum*) crop in degraded Alfisols of Southern India, which is otherwise a monocropped area (Fig. 1.2).

Figure 1.2. Possibility of second crop horse gram in post rainy season with maize residue cover in conservation agriculture experiment in monocropped dry ecosystem at Hyderabad, India (Ch Serinivasarao et al., 2013).

1.5 Conservation Agriculture and Resource Conservation Technologies

Generally, the terms "conservation agriculture" (CA) and "resource conservation technologies" (RCTs) are used as if their meanings are similar, but they differ greatly. The RCTs refer to those practices that enhance resource- or input-use efficiency. New varieties that use nitrogen more efficiently may be considered RCTs. Zero or reduced tillage, and laser land levelling practices that save fuel and improve plot-level water productivity (WP) are considered as RCTs. Other RCTs at various stages of investigation, development and adoption include raised beds, and use of leaf colour charts for guiding N application. In contrast, CA practices will only refer to the RCTs with the three interrelated principles as discussed earlier. The distinction is important because some RCTs, while attractive in the near-term, may be unsustainable in the longer-term. For example, the use of zero tillage without residue retention and without suitable rotations which, under some circumstances, can be more harmful to agro-ecosystem productivity and resource quality than a continuation of conventional practices. However, the specific components of a CA system (establishment methods, farm implement selection, crops in the rotation, soil fertility management, crop residue and mulch management, germplasm selection, etc.) tend to be different across environments.

1.6 Genotype x Environment x Management Interaction in CA

Crop production with CA, if applied properly as per site specific demand, can help farmers to produce enough additional food for the burgeoning populations. The higher productivity realized with CA under different cropping systems can be further consolidated through the development/selection of appropriate cultivar for the defined agro-ecosystem. There is a need that the genetic variability present in the germplasm is explored for designing cultivars for good crop stand establishment under CA environment and use genotype x management interactions. Studies show that performance of genotype was modified by the tillage system suggesting that selection under CA should be considered in crop improvement programs. This consideration not only applies to genotype development but will also assist the identification of physiological traits that enhance system crop performance under CA. There is some evidence regarding the relative performance of different genotypes under CA pointing at the importance of two traits in particular: early vigour (as unploughed fields tend to have a higher bulk density) and resistance to diseases – fungal diseases in particular. Tailoring efficient genotypes for CA is important as those bred for conventional agriculture may not do well. Varieties for CA should have faster root growth with thicker and less distorted than developed for conventional agriculture.

1.7 Potential Benefits Associated with CA

CA is climate-smart; promotes sustainable agricultural production; and helps to cope with the vagaries of climate change such as reduced or heavy rainfall. CA has a great potential for all crops, agro-ecological regions and farm sizes. Several studies conducted across the production systems under varied ecologies have revealed potential benefits of CA-based crop management technologies. CA improves soil health (Ward et al., 2018; Jat et al., 2018) and reduces soil erosion (Johansen et al., 2012; Pittelkow et al., 2015; Ward et al., 2018). It is associated with increased drought tolerance, increased water infiltration and retention, enabling efficient use of the available water for crop production CA contributes to carbon sequestration and reduction of GHG emissions. In the long run, CA increases food household profits by increasing and stabilizing agricultural yields, reducing cost of production and helps in bringing down farming labour demands when planting is mechanized and herbicides used for weed control (Johansen et al., 2012; Kassam et al., 2009), and enabling early land preparation (Farnworth et al., 2016) and timely planting (Kassam et al., 2009; Ward et al., 2018).

The main benefits derived from CA during the first phase of CA adoption are a reduction in labour, time and draught power required for tillage. Improvements in soil health are expected to begin from the third year of CA adoption when initial increases in soil fertility result in enhanced crop yields. The profitability of CA continues to increase with the maximum economic, agronomic and environmental benefits expected when the system is well established six to seven years after CA adoption. Furthermore, improvements in water and soil quality have also been attributed to CA. The full benefits of CA take time and in fact, the initial transitional years may present problems that may influence adoption. Three to seven years may be needed for all the benefits to take hold. In the meantime, however farmers get the benefits of saving on costs of production and time and usually get better yields than with conventional systems. Weeds are often a major initial problem that requires integrated weed management over time to get them under control. CA, if practiced correctly, has the potential to improve food security and nutritional status for farming households. Firstly, higher yields will provide more food for the family to eat directly, and any surplus can be sold and the cash used to buy other dietary requirements. Secondly, by establishing the practice of intercropping or rotating with legumes, households benefit from a mixed diet.

i. Economic benefits:

Cost of production under CT is almost always significantly higher than with CA, primarily because of energy and labour costs associated with multiple passes of land preparation. Across many studies, an income advantage of approximately $100 USD/ha can be expected for CA wheat (Keil et al., 2015). Lower cost reduction in CA is attributed to savings on account of diesel, labour and input costs, particularly weedicides. Lower production costs including the lower cost of investment and maintenance of machinery are due to reduce tillage operations and less wear and tear on the machinery in the long term. This is a key factor contributing to rapid adoption of CA technology. Savings of 30–40 percent in time, labour and fossil fuels compared with the conventional agriculture are reported. It is estimated that wide dissemination of CA could offset as much as 16% of worldwide fossil fuel emissions. Experimental results and farmers experience indicate that considerable saving in water (up to 20-30%) and nutrients are achieved with CA.

Table 1.2. The effects of mulching on soil evaporation, grain yield and water-use efficiency of wheat and maize

Crop	Treatment	Evapo-transpiration (mm)	Soil evaporation (mm)	Grain yield (g m^{-2})	WUE (kg m^{-3})
Winter wheat	Mulch	367	75	714	1.94
	No mulch	390	117	669	1.72
Maize	Mulch	386	86	712	1.84
	No mulch	431	129	666	1.55

Source: Deng et al., 2006.

ii. Yield benefits:

In most semi-arid regions, CA will increase yields due to early planting compared to the conventional agriculture when planting is late. CA is known to increase productivity and stable yields, profits. CA therefore, contributes to food security at household and national level. Crop yields and consequently food production in many parts of the African continent are actually falling. The major cause is attributed to poor soil fertility often caused by extractive and exploitative farming methods. The intensive tilling of the soil has resulted in severe soil erosion and land degradation. CA where it has been implemented has shown a high potential to reverse this trend. CA based rice-wheat and maize-wheat system showed 11 and 14% increase in yield, 31% and 71% reduction in irrigation water applied and 30 and 50% reduction in energy use compared to conventional till rice-wheat system (Table 1.3). Similarly, CA systems increased SOC by 22-26% after three years compared to conventional till rice-wheat system (Table 1.3).

iii. Crop Diversification Opportunities

Adopting CA system (including planting on raised beds) offers opportunities for crop diversification. Cropping sequences/rotations when adopted in appropriate spatial and temporal patterns can further enhance natural ecological processes which contribute to system resilience and reduced vulnerability to yield reducing disease/pest problems. Many crops like maize, wheat, mustard, chickpea, pigeon pea, sugarcane, etc., perform better under CA (permanent beds) compared to conventional agriculture.

iv. Soil moisture conservation benefits:

Surface residues acting as mulch, moderate soil temperatures, reduce evaporation, improve biological activities and provide more favorable environment for root growth, the benefits which are traditionally sought from tillage operations.

Lower soil water evaporation and conserves soil moisture: by keeping the soil covered by crop residues. The improvement in water infiltration into the soil increases the amount of moisture for the crops. Because water is a scarce commodity in many parts of Africa, its conservation and sustainable use is important to farmers. Increases water and nutrient use efficiency. Further, CA can also help in reducing water stress in dry years and reduces the risk of crop failure. Mulching with crop residues can improve water-use efficiency by 10–20% through reduced soil evaporation and increased plant transpiration.

The effects of CA on crop yield generally decrease with increasing annual precipitation and with increasing the mean annual temperature. The findings over IGP have demonstrated that CA increased system productivity over conventional and ZT without residue. Residue management in CA systems (surface retention) improves soil health, reduces GHG emission and lowers canopy temperature at grain filling stage mitigating terminal heat stress in wheat.

v. Soil health benefits:

ZT when combined with surface managed crop residues sets in the processes whereby slow decomposition of residues results in soil structural improvement and increased recycling and availability of plant nutrients. Increased soil carbon levels; sequestration of carbon. CA reverses the soil degradation through reduced soil erosion, and improved soil health (physical, chemical and biological condition) which affect crops performance. Reduced runoff due to increase water infiltration, soil erosion by wind and water by up to 90%. Permanent soil cover provides constant supply of food to the soil microorganisms and alter the micro-climate in the soil leading to improvement in biological activities and shift in microbial population towards more beneficial to crop growth and soil biological activity and biodiversity.

vi. Environmental benefits:

Reduction in GHG emissions, particularly lower CO_2 emission (one of the gases responsible for global warming) as CA requires less fuel. C sequestration and build-up in soil organic matter constitute a practical strategy to mitigate GHG emissions and impart greater resilience to various climatic stresses (drought, excess water, cold and high temperature) and climate change adaptation. CA provides an excellent opportunity to maintain crop residues as mulch thereby eliminates burning of crop residues which contribute to large amount of GHGs (like CO_2, CO, NOs, SO_2) and large amount of particulate matter (PM10), reducing human respiratory ailments, and the death of beneficial soil fauna and micro-organisms. Burning of crop residues, also contributes to considerable loss of plant nutrients, which could be recycled when properly managed.

Increased resilience to various climatic stresses (drought, excess water, cold and high temperature) and climate change adaptation and mitigation. Increased water harvesting in CA helps crops survive mid-season dry spells that are a recurrent feature of semi-arid areas. CA outperforms conventional practices in high rainfall areas and during years when the rains are good. Adopting CA offers opportunities for crop diversification can enhance ecological processes which contribute to system resilience and reduced vulnerability to yield, reducing disease/pest problems. It has the potential to halt and reverse land degradation and could be a major part of the package for sustainable land management.

Above benefits will accumulate over time since there are significantly greater improvements in the second year of implementation. Some of these gains will become obvious during the first season of implementing CA, while others take time to materialize. In some cases three to seven years may be needed for all the benefits to be achieved. Some benefits of CA implementation, such as soil water content and infiltration, are evident within the first year of CA implementation. Soil physical and biological health also takes time to develop. Soil fertility improvement under CA systems can be quite slow due to the length of time required to sufficiently increase soil organic matter content. Sometimes, it takes between 2 and 5 years for yield benefits to become apparent, in part due to farmers becoming more experienced with applying CA practice. Other benefits such as improved profitability, labor reductions, and increased water conservation can additionally incentivize farmers to adopt CA in the short term and continue practicing it. The benefits of weed suppression often ascribed to crop residue mulching require thick of mulch which are unavailable under smallholder farming in semi-arid Africa. There are reports of increases in herbicide use and occasional tillage in smallholder CA. However, these weed problems are mainly linked with sub-optimal CA practices because under CA weed pressure decreases and management improves after the initial two years. The magnitude of benefits of CA based technologies tends to be site and situation specific and cannot be overly generalized across farming systems and the regions.

Table 1.3. System yield, irrigation water and energy saving, and soil organic carbon (SOC) content in different scenarios (3 years average; 2009-2012).

Treatment	Residue management	System yield (Rice Equiv.)	Irrigation water (mm)	Energy use (MJ ha-1)	SOC (%)
Conventional rice-wheat (RW) system	All residues removed	13.0	2687	73832	0.46
CA based RW-mungbean system	100% rice and mungbean residues, and 25% wheat stubbles retained	14.8	1793	51582	0.56
CA based Maize-wheat mungbean	65% maize, 100% mungbean and 25% wheat stubbles retained	14.5	766	36457	0.58

Source: Gathala et al. (2013)

The increase in crop yields under CA can be attributed to: (a) conservation of soil moisture and nutrients; (b) improved soil water infiltration; (c) improved soil biological activities and nutrient cycling; (d) better weed control; (e) improved soil quality through increased soil organic matter concentration; and (f) regulation of soil temperature thereby minimizing high temperature effects during wheat maturity.

1.8 Origin of Conservation Agriculture in the world and Relevance in Developing Countries

Intense wind erosion known as the 'dustbowls' in mid-west United States and the Canadian Prairies in the 1930s led to the concept conservation tillage, which is based on reducing tillage and keeping soil covered (minimum 30%) aimed at soil protection. But it was not until the 1960s for no-tillage to enter into farming practice in the USA. However, suitable herbicides became a limiting factor for the development of conservation tillage systems. The problem was solved with the appearance of the herbicides paraquat and diquat in the late 1950s. With these products, it was not necessary to till the soil any more to control weeds, since they were completely eliminated without causing any risk for the following crops. In the early 1970s no-tillage reached Brazil, where farmers together with scientists transformed the technology into the system which today is called CA. Yet it took another 20 years before CA reached significant adoption levels in North America and Brazil. During this time farm equipment and agronomic practices in no-tillage systems were improved and developed to optimize the performance of crops, machinery and field operations. From the early 1990s CA started growing exponentially, leading to a revolution in the agriculture of southern Brazil, Argentina and Paraguay. During the 1990s, increased levels of awareness and adoption in a number of African countries such as Zambia, Tanzania and Kenya as well as in Asian countries, particularly in Kazakhstan, China and India. In India, CA technology is more relevant in the higher yielding, more mechanized areas of north-western India, where mostly land preparation is now done with four-wheel tractors. The basis for this technology is the inverted-T openers. However, in order to extend the technology in other parts, equipment for 2-wheel hand tractors and bullocks is being modified. This usually occurs after manual harvesting. Where combine harvesting is becoming popular, loose straw and residue creates a problem for the inverted-T opener. Future strategies will look at alternative machinery and techniques to overcome this problem. Leaving the straw as mulch on the soil surface may be very beneficial to early establishment and vigour of crops planted with ZT machines and for soil moisture conservation, water infiltration and erosion. Significantly fewer weeds are found under zero-tillage compared to CT.

The total area under CA in 2009 is estimated to be 106 million hectares and has steadily increased to about 180 Mha in more than 50 countries. Currently, efforts have focused on expanding CA among smallholder farmers in Africa and South Asia.

Area under CA cropland has expanded at an average rate of about 10 M ha per year since 2008-09. USA is leading with about 27 million hectares. The current area under CA in India is around 1.5 M ha and is expanding rapidly. In China, the adoption of CA increased during the last few years and the technology has been extended to rice production system (6.7 M ha). In Africa, CA adoption is still in the initial phases. In South Asian Indo-Gangetic plains (IGP) extending across India, Pakistan, Nepal and Bangladesh, in the rice-wheat (RW) system, there is large adoption of zero-till wheat on about 5 M ha area but only limited adoption of permanent no-till systems and full CA. Despite CA's promise, its adoption has been slow in many countries including India and Africa. All types of crops can be grown adequately in CA. Currently, only 0.3% of farmers in Africa practice CA in ways that meet the FAO specifications and only 0.8%, if the CA principles are applied in any combination and intensity (Brown et al., 2018). Overall, the practice of CA is much less common in West Africa compared to the North America, Australia and Southeast Asia (Pittelkow et al., 2015; Ward et al., 2018).

References

Brown, B., Llewellyn, R. and Nuberg, I. (2018). Global learnings to inform the local adaptation of conservation agriculture in Eastern and Southern Africa. Glob. Food Security 17, 213-220.

Ch. Srinivasarao, B. Venkateswarlu, R. Lal, A.K. Singh, S. Kundu (2013). Sustainable management of soils of dryland ecosystems of India for enhancing agronomic productivity and sequestering carbon. Adv. Agron. 121, 253-325.

Deng, X.P., Shan, L., Zhang, H. and Turner, N.C. (2006). Improving agricultural water use efficiency in arid and semiarid areas of China. Agri. Water Manage. 80, 23-40.

Farnworth, C.R., Baudron, F., Andersson, J.A., Misiko, M., Badstued, L. and Clare M. Stirling, C.M. (2016). Gender and conservation agriculture in East and Southern Africa: towards a research agenda. Int. J. Agric. Sust.14, 142–165.

FAO (2012). Conservation Agriculture. Food and Agriculture Organization Available online: www.fao.org/conservation-agriculture/en/ (accessed on 23 July 2018).

Gathala, M.K.., Kumar, V., Sharma, P.C., Saharawat, Y.S., Jat, H.S., Singh, M., Kumar, A., Jat, M.L., Humphreys, E., Sharma, D.K., Sharma, S. and Ladha, J.K. 2013. Optimizing intensive cereal-based cropping systems addressing current and future drivers of agricultural change in the north-western Indo-Gangetic Plains of India. Agric. Ecosys. Environ. 177: 85- 97.

Gathala, M.K., Ladha, J.K., Kumar, V., Saharawat, Y.S., Kumar, V., Sharma, P.K., Sharma, S. and Pathak, H. (2011). Tillage and crop establishment affects sustainability of south asian rice-wheat system. Agron. J., 103, 961-972.

Govaerts, B., Verhulst, N., Castellanos-Navarrete, A., Sayre, K.D., Dixon, J., Dendooven, L., 2009. Conservation agriculture and soil carbon sequestration: between myth and farmer reality. Crit. Rev. Plant Sci. 28, 97–122.

Gupta, R., Gopal, R., Jat, M.L., Jat, R.K., Sidhu, H.S., Minhas, P.S., and Malik, R.K. (2010). Wheat productivity in Indo-Gangetic plains of India during 2010: Terminal heat effects and mitigation strategies. PACA Newsletter. 14, 1-4.

Harford, N. and Breton, J.L. (2009). Farming for the Future A Guide to Conservation Agriculture in Zimbabwe. Zimbabwe Conservation Agriculture Task Force.

Jat, H.S., Datta, A., Sharma, P.C., Kumar, V., Yadav, A.K., Choudhary, M., Choudhary, V., Gathala, M.K., Sharma, D.K., Jat, M.L. and Yaduvanshi, N.P.S. 2018. Assessing soil properties and nutrient availability under conservation agriculture practices in a reclaimed sodic soil in cereal-based systems of North-West India. Arch. Agro. Soil Sci. 64: 531-545.

Jat, M.L., Saharawat, Y.S. and Gupta, R. (2011). Conservation agriculture in cereal systems of south Asia: Nutrient management perspectives. Karnataka J. Agric. Sci. 24, 100-105.

Johansen, C., Haque , M.E., Bell, R.W., Thierfelder , C. and Esdaile, R.J. (2012). Conservation agriculture for small holder rainfed farming: Opportunities and constraints of new mechanized seeding systems. Field Crops Res. 132, 18-32.

Kassam, A., Friedrich, T., Shaxson, F. and Pretty, J. (2009). The spread of conservation agriculture: Justification, sustainability and uptake. Int. J. Agric. Sust. 7, 292–320.

Keil A, D'Souza A, McDonald A. (2015). Zero-tillage as a pathway for sustainable wheat intensification in the Eastern Indo-Gangetic Plains: does it work in farmers' fields? Food Security.7, 983–1001.

Mandal, K.G.; Misra, A.K.; Hati, K.M.; Bandyopadhyay, K.K.; Ghosh, P.K.; Mohanty, M. Rice residue management options and effects on soil properties and crop productivity. J. Food Agric. Environ. 2004, 2, 224–231

Nyanga, P. H. (2012). Food security, conservation agriculture and pulses: Evidence from smallholder farmers in Zambia. J. Food Res. 1, 120-126.

Palm, C., Blanco-Canqui, H., DeClerck, F., Gatere, L., Grace, P., (2014). Conservation Agriculture and ecosystem services: An_ overview. Agric. Ecosys. Environ. 187, 87-105.

Pittelkow, C.M., Liang, X., Linquist, B.A., van Groenigen, K.J., Lee, J., Lundy, M.E., et al. (2015). Productivity limits and potentials of the principles of conservation agriculture. Nature 517(7534), 365–368.

Sidhu, H.S., Singh, M, Yadvinder-Singh, Blackwell, J., Lohan, S.K., Humphreys, E., Jat, M.L., Singh, V. and Sarabjeet-Singh. 2015. Development and evaluation of Turbo Happy Seeder to enable efficient sowing of wheat into heavy crop rice residue in rice-wheat rotation in the IGP of NW India. Field Crops Res., 184: 201-212.

Ward, P.S., Bell, A.R., Droppelmann, K. and Benton, T. (2018). Early adoption of conservation agriculture practices: Understanding partial compliance in programs with multiple adoption decisions Land Use Policy 70, 27-37.

Suggested reading material

Brouder, S.M. and Gomez-Macpherson, H. (2014). The impact of conservation agriculture on smallholder agricultural yields: A scoping review of the evidence. Agric. Ecosyst. Environ. 187, 11–32.

Corbeels, M., Graaff, D.J., Hycenth Ndah, T., Penot, E., Bauon, F., Naudin, K., Anieu, N., Chirat, G., Schuler, J., Nyagumbo, I., (2014). Understanding the impact and adoption of conservation agriculture in Africa: a multi-scale analysis. Agric. Ecosyst. Environ. 187, 155–170.

2 Agricultural Mechanization and Conservation Agriculture

2.1. Introduction: Importance and Definition

Agricultural mechanization involves all the field operations such as tillage and seedbed preparation, fertilizer application, drilling of seeds, transplanting, pest and disease control, weed control, harvesting/threshing and in-field transport of the crop. It also covers the manufacture, distribution, maintenance, repair and utilization of tools, implements, and powered machinery as inputs, from simple and basic hand tools to more sophisticated and motorized equipment, to achieve agricultural production. Agricultural mechanization involves the application of different power sources (human muscles, draught animals and engines). Engine powered machines represent the highest level of mechanical technology in agricultural mechanization. Mechanization eases and reduces hard labor (drudgery), relieves labor shortages, improves productivity and timeliness of agricultural operations, improves the efficient use of resources, enhances market access and contributes to mitigating climate related hazards. Where the conditions for the use of tractors and large machinery are suitable, investment in agricultural mechanization has proven to be profitable. Without proper mechanization, agricultural productivity will not increase even in the smallholder. Agricultural mechanization provides the basic tools for seedbed preparation, planting, weeding, irrigation, pest/disease control, harvesting, transportation, processing and storage, by which the drudgeries and inefficiencies involved are reduced or eliminated in order to accelerate and enhance agricultural productivity. In order to achieve Sustainable Development Goals (SDGs) in goal number twelve – SDG12, there is need to sharply improve labor and land productivity in the smallholder farming sector which produces up to 80% of the food in developing countries. The use of increased levels of mechanization is one of the most important means of achieving sustainable food production.

The application of CA principles to smallholder agricultural production situations requires some level of mechanization. The development of specialized machines and techniques for CA is more protective of the environment which maintains a permanent crop cover on the soil and uses direct seeding through the vegetative cover. The CA mechanization is plagued by various challenges related to product, technology, markets, operations, legislation, policy framework and other related areas which pose a serious impediment to the growth of the industry.

It is important to identify the correct strategies for increasing mechanization in respective countries with particular emphasis on increased production, farmers' livelihoods, and environmentally sustainable options. Use of seeding, harvesting, threshing and processing machines will reduce harvest and post-harvest losses. The type and degree of mechanization should be decided by the farmer to best suit his business and his own particular circumstances. Use of farm machinery, in contrast with other inputs such as seed, fertilizer, and chemicals, requires an initial higher capital investment. It becomes very imperative that mechanization strategy must be very clear and concrete in CA. We must have an idea about which machine to use and when. For example, immediately after harvesting rice there is proper enough moisture in the soil and we need to plant wheat using a suitable ZT planter. Similarly, another equipment of similar type known as Happy Seeder. which can seed into the rice residue and cuts in the front certain portion of the small stubbles which are there (Sidhu et al., 2015). The no-till seeding, weed control and cover crop management practices required by CA call for specific mechanized processes. The availability and affordability of these options are of paramount importance if CA is to be adopted, and the acquisition of specific equipment may often be beyond the means of individual smallholder farmers. Our contention is that a cadre of well-equipped and well-trained CA mechanization service providers will be an attractive solution to multiple problems. In this way, smallholder farmers gain access to CA mechanization services, and service providers can make a living by deploying equipment that would usually be too expensive for an individual farmer to afford and justify, over a number of farms. By providing access to the necessary technical and business planning skills, interested farmers (and others) could be encouraged to invest in CA machinery and offer custom hire service of benefit to many others in the smallholder farming community.

2.2 Rationale for Mechanization

- Mechanization improves the quality of field operations (e.g. row planting, more precise plant population, seed and fertilizer placement, efficient utilization of soil moisture during planting window)
- Mechanization helps in timeliness of operation. It is especially important for planting where delays can have a serious negative impact on final crop yields and for harvesting and threshing where there is labor shortage
- Reduces drudgery and increases labor productivity
- Increases agricultural productivity

In order for farmers to have access to farm tools, machinery and equipment, there needs to be in place a whole complex system of manufacture, importation, retail outlets, support, provision of spare parts - the so-called supply chain - as well as the availability of advice and guidance for farmers. Therefore, the development and use of mechanization as an input to agriculture is a complex and long-term process and calls for a correspondingly long term, consistent effort. In order to ensure agricultural mechanization is successful, reliable provision of spare parts, fast repair services, operating materials and fuel or energy must be guaranteed. Financial services, including loans for customers and suppliers, and leasing models can make mechanization more accessible, and professional competence should be boosted via training courses, either via the private or public sector

The benefits of mechanization rely on the availability and the use of other complementary inputs such as improved seeds, fertilizers and water. Moreover, poorly selected or misapplied agricultural machinery can damage, rather than enhance, environmental resources, especially soils. Smallholder farmers require specialized mechanization services that are both environmentally friendly and productivity-enhancing. Appropriately -trained and equipped mechanization service providers can meet this critical need.

2.3 Mechanization in Smallholder Farms

The production of food in developing countries is generally very labour intensive particularly in smallholder agriculture. Only limited progress in agricultural mechanization has been achieved in terms of increased number of machines and market expansion in post-independence Africa. Man power based hand tools have implicit limitations in terms of energy and operational output. Further, they reduce the timeliness of farm operations and limit the efficacy of essential activities such as cultivation and weeding, thereby reducing crop yields. Also, the day to day drudgery of farming is a major contributory factor in the migration of people, particularly young people, from the rural countryside to the prospect of a better life in towns and cities. Services related to farm machinery (manufacturing, assembly, repair, maintenance, financing, etc.), if sufficiently developed, are also great sources of job creation.

Several factors have been attributed to limited mechanization among smallholder farmers in many parts of India and West Africa. They include:

Thin markets that limited access to machinery and spare-parts supplies, missing institutions especially those that would be required to ensure adequate technicians and skilled personnel to operate and repair farm machinery, governance challenges such as political interest, elite capture, incompetence and corruption that constraint the government and hinder private sector’s involvement in machinery importation, among others.

Majority of the farmers are using poor quality and inefficient locally available farm equipment like irrigation pumps, harrows, cultivators, seed drills, sprayers, threshers, etc. The use of such equipment results in avoidable wastage of the scarce farm inputs and natural resources. The manufacturers producing higher quality efficient/precision equipment at higher costs are struggling for survival as subsidy provided under various government schemes promotes lower cost equipment of poor quality. The changing agricultural sector and the challenges faced by smallholders in developing countries, especially in SSA and West Africa, call for the need for farm mechanization suited to smallholder farming. For example, conventional four-wheeled tractors (4WTs) and tractor operated CA machines may not feasible for many smallholders owing to their high capital costs, unsuitability for fragmented holdings as well as farm topography and slope. More appropriate technologies such as two-wheeled tractors (2WTs) and their requisite accessories may be needed.

As smallholder agriculture become more commercial and modern, there is need for strategies to promote diverse types of mechanization technologies along the value chains. Addressing declining farm power (agricultural mechanization) can be achieved by decreasing power demand through power saving technologies or/and by increasing farm power supply through appropriate mechanization. Land preparation is the most energy demanding farming operation in rain-fed agriculture and the ZT would cut energy requirements by about half compared to mouldboard or disc ploughing. Reduced or no tillage would also make it possible to use low powered, affordable and easy to maintain 2WTs. Indeed, 2WTs are becoming more available in the eastern India and Africa. In recent years, by means of development programmes and other incentives, governments of many African countries have been encouraging farmers to make increasing use of agricultural machinery. Unfortunately, these efforts mostly have little impact on overall production. The underlying reason for this was a failure to understand the effect of structural adjustment on the agricultural tools and machinery markets particularly for those items that were imported. This decline has had an adverse effect on the development of agricultural mechanization in general and the emergence of the private sector in particular.

How to bring mechanization to smallholders?

- Break the vicious circle of land compaction, need for ploughing, destruction of organic matter
- Need to tailor production methods (farm power, pre-planting, planters, weed management options etc.)
- Need to explain that overall productivity is more than land productivity (yields)
- Need to acquire, collect and share know-how for local conditions
- Make information more accessible: extension work, advice, support and promotion
- Only through the private sector
- Incorporate gender-norm change at the highest level of project design;
- Decrease women's opportunity costs and build women's confidence;
- Distribution and aftersales services through private sector. Continue developing and supporting private sector driven distribution with targeting potential areas to build model.
- Local manufacturing and import. Targeting implement/machinery for local manufacturing'
- Institutionalization of standard; and quality check and control
- Develop continuously the business case and skills of mechanics and Service Providers at regional and national levels

Training farmers for mechanization

Effective utilization of farm machinery requires building new skills among farmers, especially those introducing machinery for the first time. Building such skills requires infrastructure, trained personnel and time. Training of traditional farmers in developing countries in the use of new machines is a difficult task. Daily and weekly maintenance processes is tedious for farmers who have never been exposed to mechanical equipment. The factors that influence the pace of mechanization are:

i. Awareness of farmers,

ii. The economic usefulness of machines,

iii. Ability of the industry to supply and service the needed equipment,

iv. Drive of the R & D institutions to provide proper designs, and

v. Support made available by financial institutions for purchase and for industrial production.

Machines of all types must be properly maintained, adjusted and operated. Machinery is capital intensive input and the economic feasibility of the equipment depends greatly on the skill, and competency of the operator. The training for farm mechanization thus involves skill building. Farmers would require training on basic operation and maintenance of new machinery. Skills need to be improved at both the user and manufacturer levels in order for equipment to be effectively designed and properly operated and maintained. Skill training will help individual farmers reduce the cost of repair and operation. It will create equipment demand for the industry by making farmers more receptive and by enabling farmers to derive full economic benefits from their equipment. The training should be hands-on and predominantly practical in the field. For example, calibration of seeders and sprayers, field operation of rippers, seeders and sprayers, routine maintenance and servicing (tractors). The training can reduce wasteful use of fuels, and help energy conservation. The training in machinery use is a skill building task.

Many African countries have a large agricultural potential which has not yet been fully developed. However, this potential cannot be fully realized without a corresponding investment in agricultural mechanization and the development of associated support systems. Achieving mechanization in an effective and sustainable manner will require much thought and careful planning. It will be necessary to identify those factors which are holding back investment by farmers in agricultural mechanization and to replace them with an enabling environment.

The first set of enabling factors, which are related to farm power demand, pre-supposes that farmers generate sufficient income to allow them to invest in new technologies; this in turn, leads to a higher demand for agricultural mechanization. The increase in income of the farmers would increase demand for farm power, machines and equipment which will lead to an increased supply of farm tools and machinery on the market. This greater supply (as well as greater competition amongst suppliers and greater choice for farmers will lead to a lowering of the capital and running costs of mechanization). Finally, this lowering of the cost of mechanization will lead back to the generation of greater demand. Government assistance for financing farm machinery, tools or equipment, is best channeled through a distributor/dealer network and not by direct importation or tendering by government or state-owned banks or other public sector organizations. Importers should be allowed free and undistorted access to markets. This will create a stable, competitive market and create a situation in which the domestic manufacturing industry will be stimulated to produce quality and functionally advanced machinery and tools at competitive prices. This will ensure a greater choice for farmers.

The dealers are an important component in the supply chain because they form the crucial link between the manufacturer and farmer. They are expected to keep stocks of spare parts, and provide service and repair facilities. An ideal farm machinery market situation is where farmers have a wide choice of makes and models of machines at competitive prices and within easy reach. Farmers need to see and inspect tools and machinery that they are thinking of purchasing and also obtain information by discussing their merits with dealers and other farmers. It may be more appropriate to view the dealer's role as marketing a range of mechanization inputs including support services and technical advice as well as machines. In the process of expanding the use of agricultural mechanization, the machinery dealers have to assume a vital role in training farmers to appreciate modern technology as well as persuading them to buy the machines and use them properly. They can also supply credit for sales of their products. This is a very effective method of making credit available because the dealer is part of the local community and therefore often knows the financial situation of his clients and is able to judge whether a particular client is credit worthy.

Service provision

The most attractive option to improve access by smallholders to CA mechanization, would be to offer the service from well-equipped and well-trained local service providers and this is the theme that will be explored now. Service providers do not necessarily have to operate on a large scale. In many African countries, the range or availability of reliable and skilled and appropriately equipped service providers with smallholder agricultural mechanization in rural areas are very limited or non-existent, especially in West Africa. Yet the need for services related to farm-power intensive and time-sensitive agricultural tasks is very high. Timely, good quality and affordable services are needed in rural areas. A potential service provider should preferably be a good farmer who is familiar with, and concerned about, agricultural practices and methods that are in line with sustainable intensification and with efficient use and care of natural resources and external inputs. However, for service providers themselves the most important challenge is to make a living and income out of the offered services. Potential service providers should have: (i) a reputation as reliable and knowledgeable farmers; (ii) be open to innovations in farming such as CA and its specific approach to mechanization and the use of alternative implements such as rippers and direct seeders; (iii) be able to operate, repair and maintain agricultural equipment. In order to become a good business person and service provider an entrepreneur needs to develop the skills needed to make the business sustainable financially.

For a service provider, feasibility studies should consider; market research, partial budgets, supply chains, credit supply, record keeping, costing of CA equipment use, balance sheets (profit and loss assessment), and business planning and marketing. The CA service providers may depend on very short agricultural seasons with maybe one- or two-month working time. This will not usually be sufficient for a valid business plan and may not justify the investment that has to be made in the equipment. Therefore, potential service providers will need to consider broadening their business into other areas for which the power source can be used. Such potential business expansion could include procurement of a tractor-drawn trailer for all year-round transport services, multi-crop threshers, tractor driven water pumps, etc. By examining the business holistically and creating business opportunities for otherwise slack periods, potential service providers will be able to develop an inclusive all-year business model that would include the CA planting services.

2.4 Constraints and Challenges

The CA mechanization is plagued by various challenges related to product, technology, markets, operations, legislation, policy framework and other related areas which pose a serious impediment to the growth of the industry. The key constraints/challenges faced by the farm mechanization industry are discussed below:

1. Small land holdings and irregular shape of fields. The smaller land sizes increase variable costs due to the enhanced time and distance.
2. High initial cost often prohibits individual ownership especially for small and medium farm holds.
3. Lack of knowledge in the aspects of operation, maintenance and repair of equipment restricts the use of farm machinery.
4. Repair and maintenance under individual ownership coupled with lack of space for shelter also constraints the use.
5. Farm mechanization is more oriented towards use of tractors and allied equipment.
6. Private-Public-Partnership (PPP) in custom hiring has been a limited success. There is lack of awareness amongst farmers on the merits of custom hiring.
7. Sub-optimal asset capacity utilization on account of crop specific requirements and uniform spread of custom hiring to all the farmers who need it.
8. Poor socio-economic condition may hinder farmers to invest in CA machinery.

References

Sidhu, H.S., Singh, M, Yadvinder-Singh, Blackwell, J., Lohan, S.K., Humphreys, E., Jat, M.L., Singh, V. and Sarabjeet-Singh. 2015. Development and evaluation of Turbo Happy Seeder to enable efficient sowing of wheat into heavy crop rice residue in rice-wheat rotation in the IGP of NW India. Field Crops Res., 184: 201-212.

Suggested reading material

Bhan S, Behera UK (2014) Conservation agriculture in India Problems, prospects and policy issues. Int. Soil Water Cons. Res. 2, 1-12.

Clarke, L. J. and Bishop, C. (2002). Farm power – present and future availability in developing countries. *Agricultural Engineering International: CIGR Journal*, 4, 1–19.

Farooq, M., and Siddique, K. (eds.). (2015). *Conservation Agriculture*. New York, Dordrecht; London:Springer International Publishing.

Jat, M.L., Chakraborty, D., Ladha, J.K., Rana, D.S., Gathala, M.K. McDonald, A. and Gerard, B. (2020). Conservation agriculture for sustainable intensification in South Asia. *Nat. Sust*. 3: 336-343

NAAS (2016). Practical and Affordable Approaches for Precision in Farm Equipment and Machinery. National Academy of Agricultural Sciences, New Delhi, India. 16p.

Oliver K. Kirui and Joachim von Braun (2018). Mechanization in African Agriculture A Continental Overview on Patterns and Dynamics. Working Paper 169. ZEF Working Paper Series, ISSN 1864-6638. Center for Development Research, University of Bonn, Germany.

3 Scale Appropriate Value Chain Mechanization for Conservation Agriculture

CA based management practices are equally important for large and smallholder farmers for increasing productivity and profitability with improved resource use efficiency. CA does not involve just a simple change in one production practice, but rather is a complex technology involving simultaneous change in many practices including machinery. Development of appropriate machinery for all types of field operations (seeding, fertilizer management, water management, residue management, irrigation, herbicide and pesticide applications) is needed for successful implementation of CA. Availability of machinery suited to local conditions is generally a major limitation in adopting CA in Asia and Africa. Although efforts have been made in developing and promoting machinery for seeding wheat in zero-tillage systems, machinery for CA is yet to be developed and evaluated for a range of crops and cropping sequences. However, small size of land holdings, poor economic condition of farmers, low seasonal use of machinery, irregular size, shape of fields, competition among machine and labour and mind set of farmers towards zero till sowing of crops are the major constraints in adoption of CA machinery in India, Bangladesh and Africa.

There are three sources of farm power utilized for the farm machinery are manual (human) and animal draft, and motorized power. The selection of implements for CA will depend on local farming systems, soil type, markets and support service considerations, technical and financial considerations, machinery outputs, working environment, and power source (tractors and draught animals) and their matching implements (including post-harvest equipment). There is need for the equipment available to practice CA during the production and post-production phases, as well as the associated power sources found in different types of mechanization systems. Through an analysis of farming systems and other factors (e.g. costs, customers and priorities), it equips participants to make optimal selections of appropriate power sources and implements, helping them to identify critical factors and understand power source and implement performance in the field. In CA, use of machinery for ploughing and subsoiling, disc, harrowing offset disc, subsoiler, mouldboard or chisel plough use will be phased out.

3.1 Land configuration and soil management machinery

3.1.1 Laser land leveling

Laser-assisted precision land levelling is a pre-requisite before the adoption of CA in any cropping system. This technology will not only conserve water and save electricity but will also improve the judicious use of other agricultural inputs like fertilizer, insecticides, pesticides and weedicides etc. The availability of water is limited in many parts of South Asia and Africa. One of the measures to improve irrigation efficiency is zero grade levelling for crop production. Zero slope fields can be flushed or drained more quickly. Level fields allow for a more uniform flood depth, using less water and reducing pumping costs. Improvement of water application efficiency at field level using precision land levelling is one of the best options for saving of water to redress the problem declining of water level. The laser land levelling also leads to increase in cultivable area by reducing the number of bunds and irrigation channels and increase in crop yields. Benefits of laser land levelling extend for many years, although some minor land smoothing may be required from time to time due to field operations and weather conditions. Some of the limitations include high cost of the equipment and need for skilled operator to set/ adjust laser settings and operate. Laser land levelling gained acceptance through empowerment of service providers (SPs) (farmers who purchase no-till equipment and then rent their services of land levelling and no-till planting to the farming community, after first using the equipment on their own farms). Training and empowerment of SPs was a big step forward. There is a large-scale adoption of laser levelling technology in North-West India through SPs and the demand of this technology is still increasing (Jat et al., 2015). Studies from North-West India reported that laser land levelling saves irrigation water, increase cultivable area by 3 to 5% approximately, improve crop establishment, improve uniformity of crop maturity, increase water application efficiency by up to 50%, increase cropping intensity by about 40%, increase crop yields (wheat 15%, sugarcane 42%, rice 61% and cotton 66%), facilitate management of saline environments, and reduce weed problems (Jat et al., 2015).

Laser levelling equipment

The laser leveller involves the use of laser (transmitter) that emits a rapidly rotating beam parallel to the required field plane, which is picked up by a sensor (receiving unit) fitted to a tractor towards the scrapper unit (Fig. 3.1).

Figure 3.1. Working of laser land leveller

The signal received is converted into cut and fill level adjustment and the corresponding changes in the scrapper level are carried out automatically by a hydraulic control system. The scrapper guidance is fully automatic; the elements of operator error are removed allowing consistently accurate land levelling. The set up consists of two units. The laser transmitter is mounted on a high platform. It rapidly rotates, sending the laser light in a circle like a light house except that the light is a laser, so it remains in a very narrow beam. The mounting has an automatic leveler built into it, so when it is set to all zeros, the laser's circle of light is perfectly level.

The main components of laser leveller include laser emitter, laser beam receiver, control box, hydraulic valve and laser eye.

i. The laser emitter unit sends continuous self-levelled laser beam signal with 360° laser reference up to a command radius of 300-400 m for auto-guidance of the receiving unit. It is mounted on a tripod stand just out the field to be laser levelled high enough to have unobstructed laser travel. Different working components & controls on the laser emitter unit includes laser emission indicator, low battery indicator, off/on power button, manual grade buttons, charge jack, battery assembly and manual mode indicator for setting of desired grades. The troublefree usage of these components should be made by following the relevant instructions mentioned in the operator's manual.

ii. The laser beam receiver mounted on the scraper, is an omni-directional (360°) receiver that detects the position of the laser reference plane and transmits it to the control box mounted on tractor. Further this control box actuates double actuating hydraulic valve for desired upward and downward movement of scraper blade to obtain level field. The grade position LED's indicate the position of the machine's blade relative to the plane of the laser light from the laser emitter. These lamps function in the same way as the grade position lamps on the control box mounted on tractor except, they flash rapidly instead of lighting solidly.

iii. The control box has been mounted on the tractor so that the operator can easily access the switches and view the indicator lamps. The control box has the main control unit for actuating the double acting hydraulic valves. The control box receives and processes signals from the laser receiver mounted on the bucket. It displays these signals to indicate the drag bucket's position relative to the finished grade. The control box is set to manual for initial adjustment of scraper blade before starting operation and when the control box is set to automatic, it provides electrical output for driving the hydraulic valve to operate scraper automatically. The three control box switches are On/Off, Auto/Manual, and Manual Raise/Lower (which allows the operator to manually raising or lowering the drag bucket).

iv. The hydraulic valve assembly regulates the flow of tractor hydraulic oil to the hydraulic controls to raise and lower the scraper blade. The oil supplied by the tractor's hydraulic pump is normally delivered at 2000-3000 psi pressure. As the hydraulic pump is a positive displacement pump and always pumping more oil than required, a pressure relief valve has also been provided in the system to return the excess oil to the tractor reservoir. The solenoid control valve controls the flow of oil to the hydraulic ram which raises and lowers the bucket. The desired rate at which the bucket could be raised and lowered depended on the operating speed. The faster the ground speed, the faster the bucket will need to be adjusted. The rate at which the bucket will raise and lower is dependent on the amount of oil supplied to the delivery line.

v. Laser eye has been mounted on the grade survey rod for obtaining the level of the field. It contains a laser receiving panel and when the laser emitted by the laser emitter panel falls in the centre of this eye a continuous beep indicates the level of that specific point w.r.t. the laser emitter. The grade of that point is then read from grade rod.

The laser beam generated by the laser transmitter is received by the receiver mounted on the laser bucket. The receiver generates voltage signal for the radiation signal. The control box receives the voltage signal from the receiver and operates the directional control valve with the help of double acting solenoid switch. The direction control valve converts the electric signal into signal of hydraulic oil. The hydraulic oil pressure actuates the ram cylinder to raise or lower the laser bucket. This continuous raising and lowering of bucket performs the continuous cut and fill operation of the soil to achieve a field surface parallel to the laser beam plane generated by the laser transmitter.

Topographic survey of field

Before laser levelling, a grid survey is performed using grade rod to identify highs and lows in the field and mean grade is found. A grid spacing of 10 m x 10 m is maintained for accurate land survey; however, this spacing can be varied depending upon the size of the field. A map is then drawn to indicate which areas are high (and requires soil to be cut) and the lows which require soil to be added. Prior to the use of laser levelling, major soil movement should be done (if required) with traditional equipment or specific machine depending upon quantum of soil movement. Following steps are to be followed for the survey:

i. Fix the laser emitter and laser eye on tripod and graded rod respectively.

ii. Adjust/align the emitter for level grading or sloped grading.

iii. Establish the level of the field using graded rod at different locations in field. While taking the level on graded rod the laser eye and the laser emitter should be in line and continuous beep should sound from laser eye after adjusting it up and down (Fig. 3.2).

Figure 3.2 Field surveying of using laser eye and laser transmitter

iv. Record the field levels at corresponding points selected in the field at every 10-15 m (as shown in survey map/sheet) depending upon size of field. More the points selected for survey more will be precision.

v. Mark the points/locations where levels have been recorded with pegs.

vi. Calculate the average field level obtained after the field survey.

vii. Locate the point similar or nearest to the average level obtained.

Operating the equipment

After locating the average level of the field required flat level or sloped grade. Following steps should be followed for benching the equipment.

i. Set the scraper blade and laser beam receiver at the location where average/nearest level exist.

ii. Set the control knob/switch on control box mounted on tractor to manual. Then set the scraper blade just above the surface located above using raise and lower switch/knob on the control box.

iii. After setting the scraper blade, adjust the laser beam receiver mounted on scraper and laser emitter at such as point where green light blinks on the control box indicating that laser beam emitter and laser receiver are in line.

iv. Set the control knob/switch from "Manual to Auto" and start operating the tractor & leveller as per survey map/sheet.

v. The operator must take minimum time and soil to pick, carry and place the soil following the survey map/sheet.

Figure 3.3. Two-wheel tractor-drawn, laser-assisted precision land leveller for small farmers (Photo by H.S. Sidhu).

Two-wheel tractor driven Laser leveller

The normal laser leveller requires 50 hp tractor for smooth operation in the field. Moreover, small holding size and irregular shapes of the field are hindrance to economic use of four-wheel tractor driven laser leveller, in eastern parts of the IGP. Efforts should be made to design and develop laser levelling technology applicable for small plot sizes (e.g., units that can be mounted onto smaller or two-wheel tractors) in the eastern IGP of India and Bangladesh and Nepal. Keeping this in view, a prototype of a two wheel tractor operated laser leveller was developed by Borlaug Institute for South Asia (BISA), Ladhowal, Punjab for the marginal & small farmers in Asia. The 2-wheel tractor operated laser land leveller in operation is depicted in Fig 3.3.

3.1.2 Raised bed (ridge) planter

Raised bed planting is a promising resource conservation technology, which was introduced for wheat in the mid-1990s and produced similar or higher yields compared with CT and sowing on the flat. Furthermore, bed planting offers many other benefits, including irrigation water saving, opportunity for mechanical weed control as well as reductions in lodging, sowing rate and waterlogging. Irrigation water use is also greatly reduced (by 30–50%) on beds in NW India (ACIAR, 2008). Permanent raised beds with stubble retention (a form of CA) add the opportunity for direct drilling of all crops in the system, with associated benefits as described under CA in Chapter 1. Permanent beds also enable crop flexibility, rapid response to market opportunities and intercropping, particularly in sugarcane. Bed size depends on soil type and cropping system (e.g. row spacing) followed and may vary from 50-120 cm. The most common size of each bed (mid of on bed to mid of adjoining bed) is 67.5 cm; 37.5 wide from top with 30 cm wide furrows (Fig. 3.5).

In the recent years, furrow irrigated permanent raised bed (PRB) planting system has proved to be one of the important components of low cost sustainable production system under CA. In CA, the beds are maintained permanent with minor shaping during seeding. For realizing the full potential of the PRB technology, sowing of crops on PRB can be done in a single pass without any preparatory tillage. The PRB planters having inclined plate seed metering systems facilitates in placement of seed and fertilizers at proper place in one operation that helps in getting good crop stand, higher productivity and resource use efficiency. It allows placement of fertilizer even in the standing crop of wheat, direct seeded rice, and maize. The PRB planter consists of double disc furrow openers along with bed shaper (Fig. 3.4). The double disc planter sows one maize row at

Figure 3.4. Bed formation/sowing with bed planter using 4-wheel tractor (left) (Ram et al., 2005) and raised bed former using 2-wheel tractor with square and cone shaper (right) (C.A. Messner, 2005)

Figure 3.5. Planting systems for wheat production (a) conventional planting system on the flat; (b) narrow-raised beds with two rows per bed; (c) three rows per bed; and (d)wide-raised beds with six rows per bed. (source: https://www.researchgate.net/ publication/221918396; accessed Sep 23 2019).

Figure 3.6. Maize crop on permanent raised beds (left) and double disc planter sowing wheat on permanent beds (right) in CA based maize-wheat system (Source: H.S. Sidhu, BiSA, Ladhowal)

centre of bed with seed to seed spacing of 20 cm and two rows of wheat at 30 cm row spacing in the presence of residues. The double disc furrow openers make a narrow slit for seed and fertilizer placement and managing maize residue thereby causing little damage to permanent beds compared to zero till tine openers (Fig. 3.6). Use of permanent raised bed planting of maize and wheat in CA based maize-wheat system (Fig,) has been successfully practiced since last six years at BISA, Ladhowal, Punjab (India). In Bangladesh and Eastern India 2-wheel tractor operated bed planters are used for making raised beds for sowing, maize, wheat, rice and other crops on permanent beds. The 2-wheel tractor operated bed planter may be used by smallholder farmers in West Africa and other developing countries for preparing and sowing on permanent raised beds (Fig.).

References

ACIAR (2008). Permanent beds and rice residue management for rice-wheat systems in the Indo-Gangetic Plains (eds. E. Humphreys and C.H. Roth). ACIAR Proceedings No. 127. Australian Centre for International Agriculture Research. Canberra, Australia.

Jat, M.L., Yadvinder-Singh, Gill, G., Sidhu, H.S., Aryal, J. P., Stirling, C. and Gerard, B. (2015). Laser-assisted precision land leveling impacts in irrigated intensive production systems of South Asia. In: Advances in Soil Science. Soil-Specific Farming: Precision Agriculture (eds. Rattan Lal, B.A. Stewart). 323-352.

Ram, H., Yadvinder-Singh, Timsina, J. Humphreys, E., Dhillon, S.S., Kumar, K. and Kler, D. (2005). Performance of upland crops on raised beds in northwestern India. 41-58. In: Evaluation and performance of permanent raised bed systems in Asia, Australia and Mexico (Eds. C.H. Roth, R.A. Fischer and C.A. Meisner). ACIAR Proceedings No. 121. Australian Centre for International Agriculture Research. Canberra, Australia.

Suggested reading material

Sayre, K.D. (2004). Raised-bed cultivation. In: R. Lal (ed) Encyclopedia of Soil Science. Marcel Dekker. Inc.

3.2: Seeding and planting machinery

The maintaining residue as mulch is one of three principles of CA. However, surface residue often interferes with the placement of seed in firm and moist soil, therefore, farmers frequently burn in the fields which are not an eco-friendly practice. ZT seed drill could be used for placing seed in the soil in anchored stubble condition after partial burning or removal of loose straw. Uniform spreading of straw during harvesting itself by mounting a device (straw management system) at the rear of combine and then using drills under loose straw condition or chopping loose as well as anchored stubbles with a rotary shredder followed by residue drills are some of the viable options. Several types of residue management units or components attached to ZT sowing equipment have been developed. Broadly, these units are designed to: (1) cut the residue ahead and along planting paths, (2) push residues sideways (in-between furrow openers) ahead of furrow opening, (3) lift the residue and throw it back on the soil after the seed has been placed and covered, and (4) bury the residue in a strip ahead of furrow opening, or a combination of any two of the above. To manage the wheat straw as fodder from combine harvested wheat fields, the straw combine is used extensively in NW India. The straw combine harvests the uncut straw as well as pick up the combine ejected loose straw from the field, chops the straw into fine pieces and blows it into an enclosed trolley trailed behind the tractor. Thereafter field could be drilled directly with rigid tines mounted inverted-T openers.

For seed planters, inclined plate planters are commonly used. However, for tiny, irregular and small seeds, pneumatic planters are being adopted all over the world. The use of costly seeds can be optimized by promoting use of inclined plate and pneumatic planters for establishing the desired plant population per hectare. The design and manufacturing process of various components of seed metering mechanisms and furrow openers need to be improved to minimize inter-row and intra-row variability of seed rate in conventional seed drills. Row-markers can be provided with commercial seed drills to assist operators to avoid overlapping. Ridge and bed planting machinery such as tractor mounted raised bed planter with quality seed metering mechanism need to be used to attain high degree of precision and conserve natural resources. Direct seeders need to be used as a resource conservation machinery for sowing wheat in paddy straw mulched fields. The seeding machinery needed for such varied conditions are discussed below.

3.2.1 Zero till Seeders and planters for four-wheel tractors

i. Zero-till seeder for anchored stubble conditions:

(Source: Dept of Farm Machinery and Power Engineering, PAU Ludhiana)

For four-wheel tractors the full range of zero-till (ZT) seeders and planters is available. The equipment is used for ZT system, requiring no previous seed-bed preparation after harvesting paddy or any other crop and sowing of wheat effectively in one operation. The ZT drill has inverted T-type furrow openers in place of shovel type furrow openers for tearing of anchored stubbles. This coulter and seeding system place the seed into a narrow slot made by the inverted-T as it is drawn through the soil by the four-wheel tractor. This drill works well for sowing of wheat in anchored rice stubbles. The coulters can be rigid or spring loaded depending on the design and cost of the machine. The performance of the ZT drill is most effective when operated in the fields with standing stubbles where the loose straw after the combine harvesting of paddy has been bailed /burned. It consists of a 6-row seed cum fertilizer drill with 1.2 m width. The seed drill has the most commonly used fluted roller mechanism. It can be operated by a 35 hp or above tractor. Its effective output is about 0.35 to 0.4 ha/h. ZT technologies for wheat seeding after removal or burning of rice residues are beneficial in terms of economics, irrigation water saving and improved timeliness of wheat sowing in comparison with CT Erenstein and Laxmi, 2008; (Lohan et al. 2018). Earlier planting is the main reason for the additional yields of wheat obtained under ZT.

ii. Zero-till Drill for seeding into crop residue

Loose straw as well as anchored stubbles are left on the surface of the field after combine harvesting of crops. The ZT seeding of crop requires drills capable of cutting through loose straw, penetration into soil and placing seed at proper depth. Generally, four types of furrow openers i.e. single disc opener, double disc opener, triple disc opener i.e. double disc opener equipped with either powered or unpowered rotary disc coulter and star wheel punch planter are being introduced in rice-wheat cropping systems. There are problems with direct drilling of wheat or any other rop into combine-harvested rice fields using the standard ZT seed drill due to: (i) straw accumulation in the seed drill furrow openers, (ii) poor traction of the seed metering drive wheel due to the presence of loose straw, and (iii) the need for frequent lifting of the implement under heavy residue conditions, resulting in uneven seed depth and thus crop establishment.

Depending on the seeder, the components of these units are designed to cut residue only or both residue and soil without causing significant disturbance to the seedbed. Cutting units, whether PTO powered or ground-driven, are normally fitted ahead of all other soil engaging components (to allow for free movement of furrow openers placed behind them; hence, minimizing blockage caused by accumulation of residues. Several types of residue cutting units are available, e.g. (1) smooth or plain, (2) notched, (3) toothed, (4) fluted and (5) bubble disc coulters, (6) power-assisted strip-chopping rotary coulter, and (7) the residue cutting unit of the Turbo Happy Seeder.

Management of rice residue is thus a serious problem, because there is very little turn-around time between rice harvest and wheat sowing in rice-wheat systems. Zero till seeder popularly known as the "Turbo happy seeder" (Figure 3.7) has been developed in India for wheat seeding to manage rice straw *in situ* by retaining it on soil surface(Sidhu et al., 2015). It is now being extensively used in the Indo-Gangetic Plains in South Asia for seeding of wheat into paddy fields. It is commercially available in North-West India from several manufacturing companies.

Figure 3.7. Turbo Happy Seeder sowing wheat into heavy loads of rice residue (Top) and wheat crop sown with Turbo Happy Seeder at 25 days after sowing (Bottom) (Photos by H.S Sidhu)

THS has been developed with flail blades mounted on a counter rotating drum that works ahead of the machine's furrow openers to clean any residue in front of tines. This helps to facilitate better drilling of seed and fertilizers into the seed rows. The cutting and shredding is achieved with hinged J-type flails mounted on a high speed (1000–1300 rpm) rotor inside the straw management drum. The flails cut (shear) the anchored residues close to the soil surface and smash them and the loose residues against serrated blades fixed on the internal walls of the straw management drum, and against the seeding tynes which are also inside the straw management drum, thus chopping and shredding them into small pieces. The THS machine cuts/shreds the standing stubble and loose straw in front of the furrow openers, retaining it as surface mulch and planting wheat in a single operational pass. At the same time, flails sweep past each sowing tyne twice per rotation, clearing the residues away and enabling the tynes to pass freely through the residues. This technology also results in much less straw deposition on the seed rows which thus leaves the seeded rows which are exposed and clearly visible, enabling accurate lining up of adjacent sowing passes. THS can also be used to direct seeding of summer moong or maize fodder immediately after wheat harvest, thus providing additional income to the farmers. THS can be operated with 45 hp 4-wheel tractor with double clutch system. Operational costs for sowing wheat are 50-60% lower with HS than with conventional sowing. The introduction of energy efficient blades and triple action straw management rotor in HS further reduced the operational power requirement by 20-25 % and improved the field capacity by 15 % (Manpreet Singh and his associates, Dept of Farm Machinery and Power Engineering, PAU, Ludhiana). The technology avoids the need for burning or physical residue removal, and enables benefits including retention of organic matter, suppression of weeds and reduced soil water evaporation (Sidhu et al., 2015). The THS technology provides all the benefits listed in section 1.8.

Figure 3.8. Knife roller with Turbo Happy Seeder for sowing wheat into maize residues (Photo H.S. Sidhu)

The THS can also be used to sow two rows of wheat in maize residues on permanent raised beds. A knife roller is attached in front of the tractor and on the rear of tractor the seeding machine can be used so that the direct drilling of next crop (wheat) can be done in single pass of the tractor. Knife roller cuts the standing maize residues into 10-15 cm pieces by shearing the maize stalks between knife roller blades and soil surface after combine harvesting of maize (Fig. 3.8). It consists of two rollers having straight knives mounted on the entire periphery of the roller. The knife roller rotates with passive power from soil surface. The rotor of THS chops the maize residues using flail blades and tine interaction. The knife roller can be operated with 45 hp tractor and field capacity of this machine is 0.8 ha h^{-1}.

iii. Tractor operated double disc planter

A two-row machine with a disc opener to break through the surface layer of trash followed by a narrow tine which although 'lifts' the soil is counteracted by a heavy roller on the back to minimize soil disturbance. The roller is fitted with flanges which are spaced so as to cause indentations in the soil into which the seed may be hand placed. The planter uses double disc openers to cut the residues coming in front of seed row. These openers are provided with two flat and sharpened discs opposed to each other and set at a small angle to the direction of travel as well as to vertical with included angle of about 100°. Double offset disc opener – cuts through residue and forms a V-shaped slot in the soil for both seed and fertilizer. The passive anti-blocking double disc planter is powered by four-wheel tractors usually operate on medium size farms for planting 4 rows maize in wheat residues in maize-wheat rotation, (Fig. 3.9). The penetration of discs is obtained by applying downward force. The seed boot is located between the two discs. The planter is equipped with inclined plate seed metering mechanism of the planter. The press wheels are attached behind the double disc openers to close the seed row for better soil seed contact to enhance the germination. The openers are used in various soil conditions, especially tilled and trashy fields. The double disc opener requires less draft (< 70 kg) but a large vertical force of 70 to 230 kg for penetration. In case of inverted-T and coulter combination, the appropriate coulter position with respect to tip of the opener, in terms of horizontal and vertical clearances, should be about 9 cm and zero or little less (-1 cm), respectively, to obtain a depth of cut of 6 cm, maximum residue cutting, minimum clogging and draft. Another ZT machine used for planting into heavy mulch is shown in Fig 3.10.

Figure 3.9. Inclined plate planter with double disc furrow openers for sowing maize/wheat in residues

(Source: BISA/CIMMYT)

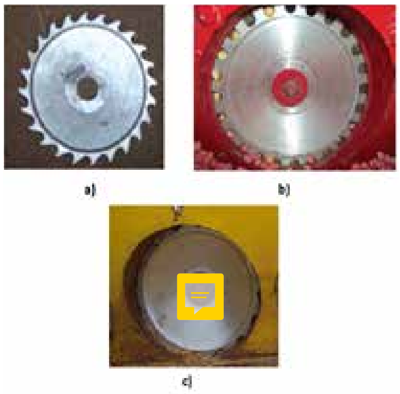
Figure 3.10. No-till direct seeding into heavy residue mulch (Photo Friedrich)

3.2.2 Multi-Crop Precision Planters

Dry seeding of rice (DSR) refers to the process of establishing a rice crop from seeds sown under aerobic conditions rather than by transplanting seedlings from the nursery in puddled fields under waterlogged conditions. The adoption of DSR cultivation as an alternative to transplanted rice significantly decreases cost of rice production. Farmers often use very high seeding rate for manual seeding of DSR or using inappropriate seed drills leading to poor yields. A planter for DSR has been developed and available for use by the farmers. The machine for DSR can maintain optimum plant to plant and row to row distance without any mechanical seed injury using a seed rate of 15-20 kg ha^{-1} at seeding depth of 2-3 cm. The planters with multi-crop inclined plate metering mechanism are more suitable for seeding rice and many other crops. Seed-metering mechanism in planting attachment is of inclined plate type with notched cells. This 4-wheel tractor driven machine is capable of maintaining seed to seed and row to spacing with very low seed injury. The chances of missing due to machine vibration are also very less compared to other systems. These planters can also be used for planting other crops like maize, cotton, soybean, groundnut, etc. by simply changing the inclined plates designed for a specific crop and adjusting row to row spacing.

There are different seed metering inclined plates for different crops as shown in Figure 3.11. The plates vary from each other in size of groove, number of grooves and shape of the grooves. The size, number and shape of the grooves are designed to suit the specific crops. To change the plates, the nut in the centre of the plate is opened and then after changing the plate it is tightened again. The planter has a working width of 1.8 m and field capacity is 0.4 ha/h. Row to row spacing and plant to plant spacing is adjustable. It saves about 60% labour and time in comparision to manual planting. The inclined plate metering box can also be attached to the existing zero till drill/ Happy seeders as an alternative to buy a separate machine. The present cost of the machine is about US $ 1000.

Figure 3.11. Types of inclined plates used in multi-crop planter, a) wheat, b) maize and c) rice



An additional inclined plate box can also be attached to the existing zero till drill as an alternative to buy a separate machine. This machine can be operated with any 35 hp tractor.

The an inclined plate metering mechanism attachment can easily be made for two-wheel tractor to increase its use and make it multi crop and multifunctional machine (Fig. 3.12). The seed metering and delivery system of the planter consists of i). Seed box ii). Inclined rotary metering plates: These rotating plates have grooves which guide the seed and drop it in to the cups. iii) Seed metering strip, v). Seed cups: v). Seed delivery pipe: and vi). Seed boot**.** The Seed boot drops the seed into the slit in the soil opened by the furrow opener. The seed metering strip is mounted on the seed box. It is attached to the seed box in such a manner that the seed box is tilted when there is an adjustment on the system. It is a strip of iron on which equally spaced holes are provided. The holes connect the strip to the seed box with the help of nut. By changing the holes, the seed rate can be adjusted. The seed rate is generally written on the corresponding hole. However, these are just indicative and for actual quantity of seed to be delivered, it is always advisable for field calibration. The seed rate may also be adjusted by putting the chain on different gears. Using the gear with lesser teeth will lower down the seed rate and vice-versa. Traditionally, seed bed preparation for maize involves several tillage operations. However, maize can be grown without any preparatory tillage with zero till/ Happy seeder having inclined plate planter attachment. Zero tillage has many benefits such as saving in diesel and time, reduced environmental pollution and saving of irrigation water in first irrigation thus resulting in reduced cost of production. This also helps in timely planting of maize over large areas.

Figure 3.12. Seed metering mechanism and its components in ZT multi crop drill

3.2.3 Tractor operated Strip-till Drill (STD)

The strip and rotary till drills have been developed that prepare the soil and plant the seed in one operation. This machine is used for minimum tillage. This system consists of a shallow rotovator followed by a seeding system. The seeding coulter does not place the seed very deep, so soil moisture must be high during seeding to ensure germination before the soil dries appreciably. The tractor can also be used with a rotavator to quickly prepare the soil and incorporate the seed after a second pass. This speeds up the planting and results in better stands with less cost than traditional methods. However, the strip and rotary till drills do a better job because the seeds are placed at a uniform depth in the single pass. The approaches taken are the use of PTO power for strip tilling with narrow rotary harrows to facilitate the penetration through the residues with a light weight seeder, or by managing the residues in front of the furrow opener with a strip-chopper leaving planted row clean. To overcome the problem of accumulation of straw and stubble in front of the tynes of conventional ZT drill, STD was developed at PAU, Ludhiana (India). Disc-coulter attachment was developed in front of furrow openers of the existing seed drill. To overcome the major limitation of its poor performance in medium and heavy soils, a rotary blade attachment was designed and developed. It is a 9-row seed-cum-fertilizer drill with a rotary blade attachment for minimum soil manipulation running ahead of the normal furrow openers (Fig. 3.13). A tractor of 35 or higher horsepower operates it. The rotary attachment consists of a frame with a rotor having '9' flanges. Each flange has 6 C-type tines (blades). The spacing between the flanges is the same as the row spacing for the crop to be planted. It can sow wheat after paddy without any prior seedbed preparation. The machine consists of a standard seed drill with a rotary attachment mounted in the front of furrow openers. The rotary unit has C-type blades, which prepare a strip of 75 mm wide in the front of every furrow opener and hence only 40 percent of area is tilled. Tilling and sowing is done simultaneously. Machine capacity is about 0.25-0.40 ha/h. Diesel saving with the use of this machine is 50-60% as compared to conventional method.

Figure 3.13. A view of tractor operated strip-till drill in operation (Photo Dept of Farm Machinery and Power Engineering, PAU, Ludhiana)

3.2.4 Seeders and planter options for smallholder farmers

Smallholder farmers in many Asian and African countries are limited by farm power shortages. These countries rely heavily on manual and animal power. The CA equipment is available for the full range of power sources, from human and animal power (rippers, jab planters, ZT planters and knife rollers) to two and four-wheeled tractors (2WT and 4WT). Manual and animal traction seeders are usually small, light-weighted, simple in design and easily manufactured, utilized and maintained. The industry is addressing the CA equipment needs for imported two-wheel tractors. For those with access only to manual labour, the chaka hoe for basin-based CA equipment has been developed and manufactured commercially and has become a popular and viable solution. Basin-based CA, the most common manual CA system in Africa, is typically practised by women.

ZT planting requires the planter to be able to cut through the surface mulch and previous crop residues that will be on the soil surface or anchored into it. The planter must be able to operate without becoming blocked with an accumulation of residues. The mulch can be penetrated or cut with vertical discs, chisel tines or jab planter beaks—or even a pointed stick. Chisel point tines are suitable in low-residue cover situations. Although development of ZT planting machinery is constantly producing improvements and refinements specifically for low-cost machines aimed at smallholder farmers are generally kept as simple as possible.

i. Manual planters

Smallholder farmers without access to draught animal power have adopted a hoe-based CA system where handheld hoes are used to prepare planting basins on uncultivated fields during the dry season. At manual technology level, besides using a planting stick or the hoe, the most common planting tool is the jab planter (Figure 3.14) which is available in different designs especially for ZT planting, mainly for row crops. Basin-based CA, the most common manual CA system in Africa, is typically practised by women. Manually operated jab planters are suitable for very small holdings and are available with both seed and fertilizer metering. The rolling type jab planter has been of marginal use only. Crop residues and other vegetative matter are retained in the area between basins. The recommended dimensions of a basin are 0.2 meters in depth, 0.3 meters in length and the same width as that of the blade of the hoe. The field capacity of the manually operated planters is around 0.06 ha h^{-1}. The size and depth of basins depend on the rainfall and water-harvesting considerations. Basins facilitate early land preparation for those who do not own animals and implements or cannot afford to hire these, a category that generally includes large numbers of female-headed households. Heavy chaka hoe enables farmers to dig compacted soils resulting from shallow ploughing and ridging over many years. This chaka hoe has an elongated, thick, strong blade and a long handle compared to the traditional hoe, enabling it to be swung with sufficient force to break through the plough pan.

Manually operated jab planters have an advantage that they are faster than using the hand hoe and one can apply the basal fertiliser and seed during planting. However, jab planters may only be used for light soils as they tend to clog and block on heavier soils. It is usually possible to regulate the number of seeds delivered per planting station and the amount of fertilizer delivered at the same time. The metering mechanism varies between different makes of jab planters, and it is important to follow the operator's instructions. Animal traction based direct planters and manual jab-planters have been introduced in African countries from the Brazil.

The punch planter can be used for planting maize, soybeans, sunflower and cowpea under CA system. It has two containers for seed and fertilizer, a punching unit to dibble the seeds in residues, a furrow opener to place the fertilizer, a press wheel to control the planting depth. The operator walks behind the planter and controls operation through handlebars. The total weight of this single row planter is 30 kg. The manual direct planter is a multi-crop planter that generally consists of a ZT tine to open a small seed row (Fig. 3.14). Seed and fertilizer are held in two separate hoppers and delivers into the slot by individual drop tubes. Mounted behind the tine is a seed and metering device drive wheel which may act as a seed covering device and press wheel. The operator walks behind the seed drill and controls operation through handlebars.

Figure 3.14. Single row punch planter (Top) and manual direct planter (Bottom)

Figure. 3.15.Manually operated seed drill

(Source: Dept of Farm machinery and Power Engineering, PAU, Ludhiana)

Manually operated seed drill is used for seeding wheat and oilseed crops like rapeseed and mustard. The machine developed by PAU Ludhiana (India) consists of seed hopper and flutted seed metering device (Fig. 3.15). The power to metering mechanism is provided by chain and sprocket through a ground wheel. Shovel type furrow opener is used for opening the furrows. Machine is operated by one person. Machine is widely used for inter-row sowing of rape seed and mustard in wheat crop or moong in sugarcane crop. It can plant 0.3 to 0.4 ha/day.

Although hand-hoe dug basins tend to increase labour demand in comparison to conventional ploughing however, the digging of planting basins is spread over a much longer period than conventional land preparation, making the activity schedule more flexible and allowing household members, especially women and children, to carry out lighter tasks. On the other hand, the reduced farm-power needs for land preparation under CA increases labour demands for weeding, thus effectively shifting labour peaks within the agricultural season (Baudron et al., 2012).

ii. Animal powered planters

Traditionally, across the African continent farmers have dominated animal or tractor-drawn ploughing. Because of farm power limitations, the deployment of power-saving animal or tractor-drawn rippers is an important benefit of CA. Mechanized, minimum tillage practices such as ripping and direct seeding generally reduce labour and recurrent capital expenses, enabling early and fast land preparation of large areas. Rippers (either animal or tractor-drawn) are a modification of ZT seeder for CA used to open a seeding slot are increasingly popular in African countries. Animal drawn chisel-tined ripper involves opening a narrow slot or furrow of about 5cm-15cm deep in the ground using an ox-drawn ripper at 90cm spacing in the dry season Fig. 3.16. It restricts soil disturbance to precise areas where the crop is to be sown resulting in minimum soil disturbance of around 10% of the area. At the start of the rains these lines can be ripped again to a depth of about 20 cm. At this time fertilizer and lime (if needed) are applied by hand to the rip line and covered by light hoeing from the rip line sides. Cereals into ZT soil are planted at an inter row spacing of 30cm. The inter-row area is not tilled and is managed as a CA system (permanent cover and effective weed control). Rippers to which furrowing wings are attached to open the furrow help to increase water infiltration. The use of rippers can be considered an interim practice to facilitate CA before eventually moving to a full direct seeding option. However, there are challenges associated with animal draught powered ripping of land because only 10% of the soil is tilled. This leads to an increase of weeds at the onset of rains thus increasing labour for weeding (Giller *et al*., (2009).

Another development is of a draught animal powered no-till planter and fertilizer distributor to replace the ripper. Commercial manufacturing of rippers (Figure 3.17) has started producing two row tractor rippers as well as animal drawn rippers, to which a planting unit can also be attached but the manufacturing capacity is still short of satisfying the demand.

Figure 3.16. Animal drawn no-till planter developed by Piket, South Africa (Bottom) and Grownet inclined plate planter (Bottom) (C. Thierfelder).

For draught animal or small tractor power, disc openers, comprising two discs either offset or of different diameters arranged so that the leading disc deflects residue, will cut through residue and form a V-shaped slot in the soil. Another option, not as popular as chisels or discs, is the rolling jab planter which comprises twin rotating off-set inclined star wheels which come together to penetrate the surface mulch and deliver the seed before opening to receive the subsequent seed.

Suitable CA mechanical technologies exist for all these technology levels, commercially available and functional. However, the actual availability of the technologies and hence the accessibility and affordability for the farmer depends very much on the existing adoption level of CA. In particular, small scale CA hand and animal traction tools and equipment so far are easily accessible for the farmers only in few countries, while single axle tractors with CA attachments can be found only in Bangladesh and eastern parts of India on the market. The actual challenge is to improve the accessibility and commercial availability of such tools and equipment in West Africa for the small holder farmers.

Figure 3.17. Animal-drawn no-till planter with double offset disc openers to better cut through heavy surface residue (Brian Sims).

iii. Seeders and planters for low power 4 WT and Two-wheel tractor

Another example of innovation in smallholder ZT planters is the Happy Seeder which has been developed for low powered 4-WTs and 2-WTs (Fig. 3.18) for use by the smallholder farmers in eastern IGP (EIGP) India and Bangladesh as human and animal labour becomes less available in the smallholder farming sector and the use of high power 4WTs is as yet not viewed as financially viable. The smaller version of THS can be mounted on the two-wheel tractor by removing the tiller attachment. However, 2WTs, whilst remaining popular in EIGP, Nepal and Bangladesh, have disadvantages over 4WTs in relation to a higher degree of operational complexity and maintenance requirements (and associated costs), but were supported with a higher level of training support provided by the manufacturers.

The ZT THS machine, fitted to the rear of a 2WT, can plant up to four rows with ZT. It has been tested in South Asia and is easily available on the market. Seeders operating with double disk furrow openers, the versions with offset disks of different diameters, which is particularly popular in Brazil. Its small version is very suited for smaller tractors, since it can cut into most residues with low equipment weights. However, for many developing countries, particularly in Asia and Africa, the double disk planters are prohibitively expensive due to the cost for the high-quality steel for the disks and the additional weight. Yet, chisel type no-till seeders and planters, as a low-cost equipment for small size tractors, have serious limitations with the residue handling, particularly when seeding small grain cereals like wheat into heavy maize or rice straw residues.

Figure 3.18. Happy Seeder coupled to a 4WT (Top) and small 2WT (Bottom) (H. S. Sidhu).

For single axle tractors one or two row precision planter attachments are available, similar to the ones used on four-wheel tractor no-till planters. In addition to those, there are low cost no-till planters available, however with a limited residue handling capacity (e.g. in Bangladesh) (Fig. 3.19). For direct seeding of small grains into no-till soil and into residues, strip-till-cum-seeders could be used based on modified power tillers leaving only the knives under the seed rows in place. Now, multi-purpose single axle tractor no-till seed drills and planters have been developed for smallholder farmers in South Asia (Bangladesh), and from there they have reached countries in East Africa where some initial steps for local manufacturing have been undertaken.

Figure 3.19. 2WT tractor operated strip till drill (Top) and multi-crop zero-till seeder for single axle tractor (Below), Bangladesh (Photo by Hossain)

3.2.5. Relay planters

Wheat planting after cotton is often delayed due to late pickings in cotton and the time involved in its seed bed preparation. The average productivity of wheat in CW system is about 30% lower compared to the productivity in the RW system of Punjab. Relay seeding of different crops in wheat and cotton offers an excellent opportunity to improve crop productivity and farmers' income.

i. Two-wheel tractor self -propelled relay planter

A two-wheel self-propelled relay seeder was developed by the Cereal Systems Initiative for South Asia (CSISA)/ CIMMYT team in collaboration with Amar Agro Industries, Ludhiana, Punjab (Fig. 3.20). Relay seeding of wheat increased cotton yield by 11-14% due to one additional picking, which was made possible with the extended growing period for about 30 days. Wheat yield was increased by 25% under relay seeding compared to conventional sowing.

Figure 3.20. Two wheel tractor with 3-row relay seeder

ii. Four-wheel tractor-operated Relay Planter

The traditional 4-WT with ground clearance of around 45 to 50 cm cannot move in the standing cotton field as the plants are about 100 to 130 cm tall. To address this issue, a high clearance platform attachment for a four-wheel tractor was developed in collaboration with BISA Punjab, India, PAU Ludhiana, India and Rajar Agricultural works, Mullanpur, Ludhiana (Punjab). This platform increased the ground clearance of the tractor to 115 cm to make the tractor move easily above the standing cotton (Fig. 3.21). The track width of mounted tractor was increased by 1.5 times the standard one (from 135 cm to 202.5 cm), which enables high clearance tractor to move in both 67.5 and 101 cm row geometries of cotton and increase the stability of the tractor. Any traditional tractor (ground clearance ~45 cm) can be converted to high clearance tractor by mounting on high clearance platform in 4 to 6 hours. The relay seeding of wheat using different furrow openers included single operation, whereas CT wheat needed five–six tillage operations.

Figure 3.21. Tractor (normal) and mounted on high clearance platform (top) and 15-row relay seeder with ZT openers seeding wheat into standing cotton (bottom) (Photos by H.S. Sidhu).

(Source: Manpreet-Singh et al. 2016b)

Net returns were 27- 37% more under relay seeding of wheat using high clearance tractor compared with the conventional wheat.

The high clearance 4-wheel tractor driven relay seeder can also be used for relay seeding of short duration mungbean (maturing in about 65 days) in to the standing wheat in the mid-March (Fig 22). Wheat should be planted in paired-row system at 15 cm instead of 22.5 cm thus leaving wide space (30 cm) after every two rows. Total rows of wheat will be same as for conventional wheat. The mungbean is planted will be planted in the middle of the wider space in standing wheat. The relay sowing of mungbean ensures pulse grain yield of about 1.0 t ha^{-1} escaping challenge from early onset of monsoon rains obstructing the harvest of the crop as experienced in the crop planted after wheat harvest in the third week of April.

Figure 3.22. Relay seeding of moong in wheat crop. Relay seeder operation in wheat (Top) and mungbean crop in wheat residues after 21 days of sowing (Bottom)

References

Araya, T., Cornelis, W.M., Nyssen, J., Govaerts, B., Getnet, F., Bauer, H., Raes, D., Amare, K., Haile, M. and Deckers. J. (2012). Medium-term effects of conservation agriculture for in situ soil and water management and crop productivity in the Northern Ethiopian Highlands. Field Crops Res. 132, 53–62.

Baudron, F.; Andersson, J.A.; Corbeels, M.; Giller, K.E. (2012). Failing to yield? Ploughs, conservation agriculture and the problem of agricultural intensification: An example from the Zambezi Valley, Zimbabwe. J. Dev. Stud. 48, 393–412.

CFU. (2009). Conservation Farming & Conservation Agriculture Handbook for Ox Farmers in Agro-Ecological Regions I & II. Lusaka: Conservation Farming Unit, (Chapter E)

Erenstein, O. and Laxmi, V. (2008). Zero tillage impacts in India's rice-wheat systems: a review. Soil Till. Res. 100,1–14.

FAO (2011). What is conservation agriculture? Conservation Agriculture. Available from: http://www.fao.org/ag/ca/1a.html.

Giller, K.E., Witter, E., Corbeels, M., and Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Res. 114, 23–34.

Lohan, S.K., Jat, H.S., Yadav, A.K., Sidhu, H.S., Jat, M.L., Choudhary, M., Peter, J.K and Sharma, P.C. (2018). Burning issues of paddy residue management in north-west states of India. Renew. Sustain. Energy Rev. 81, 693–706.

Manpreet-Singh, Mahal, J.S., Sidhu, H.S., Manes, G.S., Jat, M.L. and Yadvinder-Singh. (2016). Development and feasibility of innovative relay seeders for seeding wheat into standing cotton using high clearance tractor in cotton-wheat system. Applied Engg.in Agri. 32, 341-352

Nyanga, P.H. (2012). Factors Influencing Adoption and area under conservation agriculture: A mixed methods approach. Sust. Agric. Res. 1, 1-14.

Sidhu, H.S., Singh, M, Yadvinder-Singh, Blackwell, J., Lohan, S.K., Humphreys, E., Jat, M.L., Singh, V. and Sarabjeet-Singh. (2015). Development and evaluation of Turbo Happy Seeder to enable efficient sowing of wheat into heavy crop rice residue in rice-wheat rotation in the IGP of NW India. Field Crops Res., 184: 201-212.

Suggested reading material

Baudron, F., Sims, B., Justice, S., Kahan, D.G., Rose, R., Mkomwa, S., Kaumbutho, P., Sariah, J., Nazare, R., Moges, G., et al. (2015). Re-examining appropriate mechanization in Africa: Two-wheel tractors, conservation agriculture, and private sector involvement. Food Secur. 7, 889–904.

FAO (1994). Testing and Evaluation of Agricultural Machinery and Equipment: Principles and Practices; Agricultural Services Bulletin 110; Food and Agriculture Organization of the United Nations: Rome, Italy, p. 272, ISBN 92-5-103458-3.

Jat, M.L.; Kapil Kamboj, B.R.; Sidhu, H.S.; Singh, M.; Bana, A.; Bishnoi, D.; Gathala, M.; Saharawat, Y.S.; Kumar, V.; Kumar, A.; et al. (2013). Operational Manual for Turbo Happy Seeder Technology for Managing Crop Residues with Environmental Stewardship; International Maize and Wheat Improvement Center (CIMMYT), Indian Council of Agricultural Research (ICAR): New Delhi, India, p. 28.

Johansen, C.; Haque, M.E.; Bell, R.W.; Thierfelder, C.; Esdaile, R.J. (2012). Conservation agriculture for small holder rainfed farming: Opportunities and constraints of new mechanized seeding systems. Field Crops Res. 132, 18–32.

Sims, B.G. (2014). Labour saving technologies for smallholder farmers; an initiative of the Gates Foundation. Agric. Dev. 21, 12–13.

Temesgen, M., Hoogmoed, W. B., Rockstrom, J., & Savenije, H.H.G. (2009). Conservation tillage implements and systems for smallholder farmers in semi-arid Ethiopia. Soil Till. Res. 104, 185–191.

3.3 Inter-culture/in-season management machinery

3.3.1. Earthing-up/reshaping openers for permanent beds

Permanent raised beds (PRB) disintegrate and lose their shape during the growing (i.e. rainy) season. The PRBs must therefore be reshaped once each year. This involves a pass with cutting disks to break up any remaining large pieces of crop residue, and reshaping shovels which reshape the bed and direct residues out of the furrows and up onto the bed (Fig 3.23 and Fig. 3.24).

Figure 3.23. Reshaping of permanent wide beds (Top) (CIMMYT, Mexico), and reshaping and sowing of wheat on permanent raised beds. (Bottom) (H.S. Sidhu)

Figure 3.24. Earthing up/weeding in raised beds (BISA, Pusa, Bihar, India)

3.3.2 Fertilizer banding/drilling

Application of fertilizer uniformly on the soil surface is known as broadcasting of fertilizer. This is done either before sowing of the crop or in the standing crop (top dressing). Fertilizer placement at a specific soil depth is an integral part of efficient nutrient management. Correct placement often improves the efficiency by which plants take up nutrients and consequently encourages maximum yields of intensively managed agronomic crops. Surface application (broadcast) of fertilizer under CA leads to more loss of nutrients resulting into poor nutrient use efficiency and environmental pollution. Therefore, proper placement of fertilizer (both in horizontal and vertical dimension) is very crucial to ensure that plant roots can absorb required nutrient during the growing period and thereby increase the NUE in CA system.

This is particularly more important for P and K due to their less mobility. To fertilize a crop row, place the fertilizer 5 cm to the side and 5 cm deeper than the seed furrow. This is called banding. When you irrigate with furrows, place the band of fertilizer between the irrigation furrow and the seed furrow. You can also place the fertilizer on one side of a seedling or on one side of a plant mid-way or alternate side of plant row through its growing period. This is called side dressing. In CT systems, generally 20-30% N is drilled at the time of planting and remaining recommended N is broadcasted in 2-3 splits depending on the type of crop.

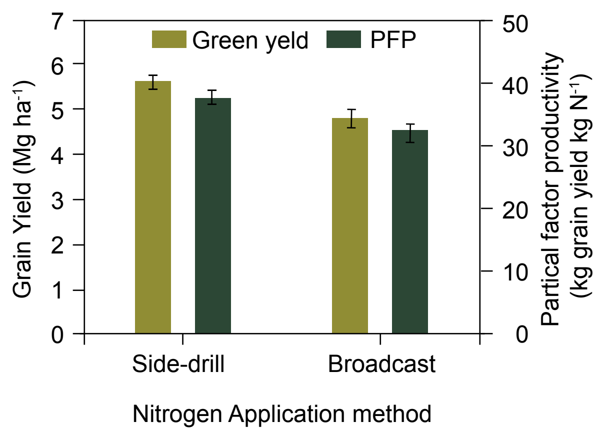
Placement near the seed-row may increase access of crops to the nutrient early in the growing season and provide a 'starter' effect that improves early growth. Methods of application of nutrient are also important to increase productivity and profitability in cropping systems. A multi-purpose double disc planter which can be used for planting of different geometry crops can be used for nutrient drilling in standing crop, especially in permanent raised beds covered with loose crop residue (Fig. 3.25).

Figure 3.25. Band placement of split applied nitrogen in wheat (Source: CIMMYT, India).

The double disc openers can place the nutrient at 5-10 cm depth near root zone in standing crop under CA or permanent raised bed system. Fertilizer cum seed drills (e.g. Happy Seeder) are available for drilling fertilizer and seeds separately or in the same furrow/row below seed in one operation at planting. By and large, the remaining dose of N is applied in two or three splits by broadcasting urea under both CT and CA systems. Drilling of fertilizers improved nutrient use efficiency, grain yield (by 670 kg/ha), profitability (by Rs. 7700/ha) of wheat. Higher grain yield and partial factor productivity of N were recorded in side-drill method compared to broadcast application in wheat in maize-wheat system of Bihar (Fig. 3.26). Drilling facilitate the deeper root systems where crops efficiently forage nutrients available in the deeper layer which reduce the leaching losses of the nutrients and deeper root system reduced crop lodging.

Sandhu et al. (2019b) reported that while uniformly broadcast method required 120 kg N ha^{-1}, similar maize and wheat yields can be achieved with 90 kg N ha^{-1} using deep placement on beds (DB) thereby saving 30 kg N ha^{-1}. DB increased maize yield by 5.4% and 10.9% compared with drilled in furrows (DF) and

Figure 3.26. Wheat grain yield and partial factor productivity (PFP) of N as affected by two fertilizer application methods in the maize-wheat systems. (Source: Borlaug Institute for South Asia, Pusa, Bihar).



broadcast, respectively. In wheat, DB and drill in furrows significantly increased grain yield by 4-7% compared to broadcast. At 120 kg N ha^{-1}, NUE of 61% and 74% with broadcast was increased to 73% and 98% with DB in wheat and maize, respectively. Both tractor and manual operated drill are available for band placement of fertilizers, particularly in widely spaced crops such as maize and cotton (Fig, 3.27).

Figure 3.27. Band placement of fertilizer in maize using tractor operated fertilizer drill (Top) and manual drill (Bottom)

3.2.3. Sprayers and Spraying Technique

Control of insects/pests and weeds depends upon the use of proper spray technology. There are different types of sprayers required for herbicide/ pesticide application which can be powered by human or animal or engine power. About 40-50% of the pesticide is generally wasted with improper manual spray, which not only adds to the cost of production but also is environmentally hazardous and harms the natural ecosystem. Sprayer is a machine used for application of fluids in the form of droplets or mist. It is used for the application of small quantity over a large area. Knapsack sprayer is most commonly used for herbicide spraying. Other examples of herbicide application technologies, not as popular as spray delivery via hydraulic nozzles, include simple weed wipers (such as the Zamwipe fabricated in Zambia) and controlled droplet application (CDA) sprayers. The CDA sprayers use much lower volumes than hydraulic nozzles and produce droplets within a narrow size spectrum for increased efficacy and reduced drift. The droplets are produced by rapidly spinning plates or cones with toothed extremities. For residue and weed management knife rollers and boom sprayers are available for animal traction. If draught animals or tractors (2- or 4-wheel) are available—either through individual ownership or via mechanization service providers—then conventional boom sprayers can be used with widths ranging up to 20 m or more. Various types of equipment are used for herbicide spray depending on the nature of crop, weed/ insects/ pests and chemical to be used, namely:

i. Knapsack sprayer

ii. Weed wiper (such as a Zamwipe)

iii. Knife roller

iv. Hand-pulled sprayer

v. Animal-drawn sprayer

vi. Tractor-mounted boom sprayer

i. Knapsack sprayer:

The most frequently used machine in smallholder CA systems is the ubiquitous lever-operated knapsack sprayer. The sprayer carried by the operator on its back is called as Knapsack sprayer. Their proper use is very essential to achieve desirable weed control results. These sprayers may be manual or powered by a battery or petrol engine. They are reasonably cheap and easily available. Mounting a shield prevents the spray from drifting onto crops, so the sprayer can be used after the crop has emerged. Knapsack sprayers are not suitable for large farms. Single and two- nozzle knapsack sprayers are used to apply common herbicides/pesticides in smallholder farmers' fields (Fig. 3.28). Spray application is also more uniform with boom. With this configuration the operator can walk well with the spray nozzles while applying herbicide uniformly over a wider boom width (usually 2 m with 4-nozzle sprayer). A hand-pulled six-nozzle sprayer is also available for chemical application. This equipment is relatively inexpensive and allows for faster application. Knapsack sprayers can be mounted on a wheeled chassis, fitted with a multi nozzle boom and hand-pulled, thus largely removing the operator from the risk of contamination. Despite the relative simplicity of its design, knapsack sprayer operators will usually benefit from training in operation, calibration and maintenance.

Figure 3.28. A single nozzle (Bottom) and double nozzle (Top) knapsack sprayers to apply herbicides in farmers' fields.

Hand-pulled sprayers: Knapsack sprayers can be mounted on a wheeled chassis, fitted with a multi-nozzle boom, and hand-pulled so removing the operator from the risk of contamination. When the wheels turn, they pump the chemical/herbicide into a boom with four or six spray nozzles. The height of the boom can be adjusted to deal with plants of different heights. They have more than two nozzles (usually 4) and a larger tank than a knapsack sprayer, so can cover a larger area more evenly. They are suitable for treating a whole field; they cannot be used to spot-spray individual patches of weeds. Because the spray is behind the operator (unlike with knapsack sprayers), there is much less risk of breathing in the spray or getting it on your skin other clothing.

Animal-pulled sprayers: Animal-powered sprayers may have up to 10 nozzles (spaced about 50 cm apart). They can be pulled by one or two animals. They have a larger capacity than hand sprayers, so are suitable for larger areas. Large-capacity boom sprayers are manufactured for animal traction.

Knife-roller: Knife-roller is used for to kill the weeds after flowering but before the seeds have matured. The best time to do this is when the weeds have reached the milk stage. And the weeds do not have a chance to produce seeds, which would be difficult to control. The knife-roller crushes the cover crop, but does not cut it up. That means the residues are not dragged along by the roller and do not get tangled in equipment. It can be operated by animal or engine power (2- or 4-wheel tractor).

Zamwipe: The Zamwipe consists of a herbicide-moistened wick (usually glyphosate) which is manually brought into contact with the weeds. The Zamwipe works best just before planting the main crop. Use it to kill weeds that have started to regrow after they are slashed, when they are 10–12 cm tall. It can also be used to control weeds in between rows of maize or sorghum, when the crop is knee high – i.e., at the same time as when farmers normally do weeding of their fields. Farmers have, however, expressed some difficulties with this implement as the flow rate is not easy to control and if the application head touches the soil the herbicide is deactivated.

Tractor mounted/self-propelled sprayer

For herbicide/pesticide spraying on a large area, both tractor- mounted or self- propelled sprayers can be used. While these sprayers can be effectively used for pre-emergence herbicide application, their use is generally impractical for post emergence herbicide application and the feasibility will depend on the soil conditions or the nature of the crop. Tractor-powered sprayers can be very sophisticated. They are suited for large farms. The main advantages of the tractor-mounted sprayer/self-propelled sprayers over knapsack sprayer are;

1. Uniform herbicide application
2. Uniform coverage and no escapes
3. Less health hazards while spraying because knapsack spraying is generally done by farmers without wearing protectants.
4. Time saving and cost effectiveness
5. Allows better field coverage with ultimately good weed control.

a. Self-Propelled Sprayer

A light weight self-propelled walk behind type sprayer is used for spraying for weedicides and chemical application on wheat, vegetables and other crops (Fig. 3.29). The machine is operated by 5 hp diesel engine and is controlled by the operator from the handle. The ground clearance of the machine is 50 cm. The boom height can be adjusted from 60 to 130 cm to suit different crops. The sprayer consists of a tank of 100 liters capacity, piston type spray pump and a boom with 12 nozzles. The nozzles are placed at a spacing of 50 cm and cover a width of about 7.0 m in one pass. A provision has also been made to adjust the track width from 90 to 105 cm. The sprayer has a capacity to cover about 15-20 acres/day when operated at a speed of 2.25-2.5 km/h. It saves about 80 percent labour.

b. Tractor-mounted boom sprayer

The advancement of technology has resulted in the development of automatic boom sprayer machines for spraying pesticides on crops like cotton, which is more vulnerable to pest/insect attack. Boom sprayer can also be used for many other crops. The power operated sprayers (e.g. boom sprayer) have nozzles that discharge minimum of 600 ml of pesticide per minute are the best for pest control. Boom sprayer covers both upper and lower side of the plant leaves with the chemical and thus is more effective in controlling pests/insects. The boom sprayer is more effective as it helps in uniform spray, with optimum pesticide/herbicide and water ratio unlike manual operated knapsack sprayer. The field capacity of the machine for cotton crop is about 4 ha per hr. Farmers can save time, labour and cost of operation as well as drudgery of spraying operation.

The sprayer can be attached to a 2-WT or 4-WT. Tractor-mounted sprayer is mostly for large farms and fields (Fig. 3.29). Requires supporting tractors and trailers for transport to storage area.

It is suitable for spraying on cotton crop or any other wider row crops. It consists of a centrifugal pump, a tank, pressure regulator valve and a boom with nozzles and spray gun fitted on a frame. The sprayer is mounted on the 3-point linkage of the tractor and drive is given through from tractor PTO through a set of gears. Boom height can be adjusted from 10 to 225 cm from ground to suit different crop height. It can cover up to 1200 cm width and has a capacity of about 2.0 ha/h at a field speed of 3.0 km/h.

i. Self-propelled High Clearance Sprayer

It is most suitable for spraying on tall crop like cotton or wider row crops. The machine has a chassis with 120 cm ground clearance, four wheels, and 20 hp diesel engine, gearbox, water tank, seats for the operator, spray pump and boom with 18 nozzles (Fig. 3.30). The boom height can be adjusted form 31.5 to 168.5 cm to suit different crops and can be folded during transport. The field speed is up to 5 km/h and the road speed is up to 25 km/h. The width of coverage is 13.5 m and it has a capacity of about 2.0 ha/h at a field speed of 3.0-4.0 km/h. Mechanical damage caused by the movement of high clearance sprayer in cotton crop is less in comparison to tractor operated sprayer.

Figure 3.29. 4-wheel tractor mounted boom sprayer (Top), (H.S. Sidhu) and sprayer attached to a Chinese 2WT (Bottom), (B. Sims).

The investment costs for such equipment are, unfortunately, beyond the financial resources of many smallholder farmers; and it is here that the potential of CA mechanization service providers becomes apparent. It may be possible to hire the service provider to spray your farm with a tractor sprayer, rather than investing in one yourself.

Figure 3.30. Self-propelled sprayer

(Source: Dept of Farm Machinery and Power Engineering, PAU Ludhiana)

Key components of spray technology

Type of nozzles, spray tips, nozzle booms, and pressure regulator of sprayer are the key components of spray technology. The most important but usually neglected aspect of the spraying system is nozzles. The nozzle performs four basic functions; it atomizes the liquid into droplets; disperses the droplets in the specific pattern; meters liquid at a certain flow rate and provides hydraulic momentum. Nozzle consists of a spray tip, strainer, and a nozzle body and a cap. The flow and distribution of the spray output is determined by the spray tip. Spray tips is the most important aspect of the nozzle. It can be flat fan, flood (cut), cone (variable or hollow). Flat fan nozzle forms a narrow, elliptical, inverted V pattern. Herbicide concentration is heavier in the centre and tapers towards the outer edge. The flat fan nozzle helps in uniform and rapid application of herbicides/chemicals. When spray is done using a single nozzle then it is desirable to use even fan nozzle because spray pattern is uniform from one end to the other end. Flat fan nozzles should be used for multiple nozzle booms. Flood jet (cut) nozzles are widely used by the Indian farmers. Here, the herbicide concentration is heavier towards the outer edge. Cone nozzles either variable or hollow are generally used for application of fungicides and insecticides. It is used for low volume spray application and produces small droplets at moderate to high pressures (500-2000 kPa). Nozzle capacity depends on the size of the nozzle tip and they are generally available with a capacity of 600 to 1200 ml/min. Low capacity nozzles are generally used in multi nozzle boom spraying. A large orifice creates the coarse droplets. The spray swath will depend on the type of nozzle and number of nozzles on the boom as well as the height of nozzle from the ground. The height of nozzle should be kept at about 30-45 cm above the soil surface so that there is not excessive overlapping as well as uncovered area. The boom should be kept at constant height and moved at constant speed.

Safety measures and maintenance of sprayers

Working with sprayers requires certain safety measures in order to ensure that occupational health is not under threat. The following are among the basic requirements:

Use protective clothing to protect the operator from contact with agrochemicals (Fig. 3.31) and wash your hands, face, body and spray equipment immediately after handling or using any agrochemical. Rinse and clean spray equipment well away from water sources such as wells, ponds or rivers. Always store agrochemicals in their original containers, well out of reach of children and animals. Dispose of containers in a deep pit, or as indicated by the manufacturer.

Figure 3.31. Protected spraying

Important hints for safe and efficient use of herbicides/ chemicals

Safe use of herbicides and is necessary otherwise it may prove hazardous to humans, domestic animals and crops or ineffective or uneconomic. For safe and effective use of herbicides consider the following points.

i. Select proper type of spraying equipment and calibrate the equipment before use.

ii. Use shields (hoods) to check or restrict drifting. Nozzles mounted inside the hood spray the row middles while the hood protects the crop from direct contact of herbicide spray and drift. Non selective herbicides like glyposhate or paraquit should be applied through hooded sprayers. It is generally done in row crops with wider spacing to avoid the contact of herbicides with crop plants which otherwise may be injuries.

iii. Ensure that the equipment is in good working condition (no leaks or blockages). Replace worn-out or defective parts.

iv. Sprayers should always be tested before use for: correct operating pressure, nozzle overlap, individual volume/time discharge (calibrated for application volume). Thorough cleaning of equipment is necessary if not to be used again for some time. Do not blow out blocked nozzles with the mouth, clean them with water or a soft probe, such as grass stem etc.

v. Make sure you know how to use the herbicide properly. Get training if you need it. Herbicides are safe as long as they are used and stored properly.

vi. Always select the herbicides based on the crops and weed flora.

vii. Dissolve the required quantity of herbicide that can be sprayed on the same day only.

viii. Apply herbicides in right amount and at the correct stage for better efficacy. When using too much of herbicide it will be wasteful and expensive or too little dose will not control weeds properly.

ix. Spray from the right height. This depends on the height of the weeds and the type of nozzle. If you are using a hand-pulled or animal-drawn sprayer, adjust the height of the boom so the spray from the nozzles covers the weeds evenly – not too much overlap, and no gaps.

x. Always use the clean drinking water to mix with herbicide and fill the spray solution in the pump through sieve carefully to filter out debris and thereby avoiding the clogging of the nozzles. While mixing in water, use wooden stick or iron rod.

xi. Early morning after dew has dried and late afternoons are suitable for spraying for greater herbicide efficiency.

xii. Always read the label carefully before using any herbicide.

xiii. Always use recommended brand of superior quality herbicides and avoid the usage of poor-quality herbicides. Poor quality herbicide will either provide the poor weed control or can damage the crop.

xiv. Buy herbicide from a certified dealer. Check the date on the label to make sure the herbicide you buy is still effective.

xv. To prevent problems of resistance it is important to avoid the use of the same herbicide repeatedly and year after year.

xvi. Do not work in strong wind. It can be dangerous for the operator, and/or may damage neighbouring crops. Strong wind can cause drift thus may make the pesticide ineffective, by blowing it away from the targets. Drift is affected by weather conditions, droplet size, height of the boom-spray, and operating pressure. Adjust drift with decreasing the pressure and increasing the nozzle capacity. The pump should normally be operated at a pressure of 250-300 kPa. Also, keep the nozzle at appropriate height as higher spray height increase the chance of drift by wind... The proper height of a boom-spray is an important factor in ensuring a complete and even coverage of the target. When spray drift is not a problem, it is best to set the height so as to get a double-coverage spray pattern.

xvii. Spray should be done on a clear day and avoid spraying during cloudy weather conditions.

xviii. While applying herbicides, drift may occur and can injure the sensitive crops. The drift depends on droplet size, wind velocity and boom height.

xix. Soil contact herbicides should be sprayed onto moist soil.

xx. Always store herbicides in their original containers, well out of reach of children and animals. Dispose of containers in a deep pit, or as indicated by the manufacturer.

xxi. Applicator should wear protective clothing (Apron, long sleeved shirt, long legged trouser, hat, mask, goggles, gloves and gum boot and socks) while spraying pesticide to protect himself from harmful effects of the pesticides.

xxii. Wash hands, face, body and equipment immediately after handling or using any herbicide. Rinse and clean spray equipment well away from water sources such as wells, ponds or rivers. After completion of spraying bath should be taken by the person. Never eat, drink, smoke or rub your eyes or face while working with pesticides.

3.4 Harvesting and Threshing Machinery

Harvesting of cereal crops especially wheat and rice is a serious problem. There is a tremendous crop loss when untimely rain is experienced. Delayed harvesting causes grain shattering due to over maturity. The standing crop in the field can be harvested with the use of reapers. Harvesting equipment may be manually operated, animal-drawn or power operated. Sickle (plain or serrated) is the most widely used harvesting tool for various crops. Animal drawn reapers have been tried and proved successful on wheat crops. Power operated machines can be reaper, mower, rotary power scythes, binder and conventional combines. A manually operated rotary power scythe (push-cutter) uses a high-speed engine for rotating the cutter blade. A rotary circular disc with plain or serrated edge accomplishes the cutting by impact force. The unit is mounted on the backside of the operator, who also activates the cutting rod. The crop is cut and laid in windrows. The output varies between 0.2 to 0.4 ha/day. Tractor front mounted reapers and mowers are also being used for harvesting various crops. It can be powered with power tiller or tractor. Combine harvesters are now becoming increasingly popular in northern India and also in other parts of country. Combines are being used mostly for harvesting crops like wheat, paddy, soybean, sunflower and other crops. Both types of combines viz. self-propelled and tractor operated are common for these crops.

3.4.1 Reaper Binders

The reaper-binder is a farm implement that improved upon the simple reaper. In addition to cutting the small-grain crop, a binder also 'binds' the harvested crop into bundles. A reaper may be classified as animal-drawn reaper, animal-drawn engine operated reaper, tractor rear mounted PTO operated reaper, power tiller operated or tractor front mounted vertical conveyer type reapers and tractor mounted reaper binder.

Animal-drawn reaper: It consists of a cutter bar of 1.05 m length. The power to drive the knife bar is given from the ground wheel by means of gear box, crank and connecting rod mechanism. As the machine is pull forward by a pair of bullocks, a reciprocating motion is imparted to the knife bar with a peak cutting velocity of about 100 m/min. The crop is cut due to shearing action. The effective field capacity of machine varies between 0.2-0.3 ha/h.

Power tiller (2WT) front mounted vertical conveyer reaper-cum-windrower and binders

A machine called vertical conveyor reaper–cum-windrower can cut the crop and lay it in the form of windrow for easy picking. It consists of a conventional cutter bar assembly, crop row dividers with star wheels, covers, pressure springs and vertical conveyor belts (Fig. 3.32 and Fig. 3.33).

Figure 3.32. Self-propelled vertical conveyor reaper-cum-binder

Figure 3.33. Power tiller front mounted vertical conveyer-reaper-windrower

Cutter bar is given reciprocating motion by crank wheel. Crop row dividers with star wheels enter the standing crop, help in lifting, gathering and guiding the crop towards the cutter bar. After the crop is cut, held in a vertical position during its passage by means of pressure springs and star wheels. Vertically held crop is then delivered towards right side of the machine in a windrow perpendicular to the direction of movement of machine with the help of lugged conveyor belt. The gearbox and windrower is coupled to the drive shaft of the prime mower. The output shaft transmits power to the shaft driving the lugged flat conveyor belts and a crank is attached at the lower end of the output shaft to operate the cutter bar through connecting rod. The serrated blade cutter bar with standard knife guards is fitted. The top lugged conveyor belt drives the star wheels on the crop row dividers. Pressure springs are fitted below the star wheels between the conveying platforms to keep the cut crop in upright position while it is being conveyed out of the machine. The power in case of power tiller units is transmitted through an intermediate shaft to the gearbox on windrower either by belt or by shaft drive. In tractor mounted models, the power to the gearbox is transmitted from PTO shaft through gearbox by a long shaft running beneath the tractor body to the front and with the help of universal joint and telescopic shaft which is connected to the gearbox. Lowering and raising of reaper is carried out with the help of hydraulic system of a tractor. In case of power tiller the machine pivots on the power tiller wheels. By pushing the handle, the cutter bar can be raised.

A front mounted vertical conveyor reaper is the most common reaper, to harvest wheat and paddy crops. It can also be used for harvesting of soybean and other similar crops. Engine operated reaper (Fig. 3.32) can be operated with a 5-6 hp engine, whereas, tractor operated reapers (Fig. 3.33) can be operated with 25-35 hp tractor. Width of cut is about 1.6 m in power tiller reaper, and about 2.05 m in tractor operated reapers. Stroke per min of cutter bar is 1225 and 1550 in case of power tiller and tractor operated reapers, respectively. Power tiller and tractor-front mounted vertical conveyer reaper windrower can cover about 0.2 ha/h and 0.4 ha/h, respectively.

Tractor Front Mounted Vertical Conveyer Reaper Windrower

It is suitable for harvesting and windrowing of wheat and paddy crops. The machine is mounted in front of the tractor and the power to the machine is provided through tractor PTO with the help of intermediate shaft running beneath the body of the tractor and a coupling shaft. Height of the cut above ground is controlled by tractor hydraulic with the help of pulleys and steel ropes. After the crop is cut by the cutter bar, it is held in a vertical position and delivered to one side of the machine by lugged belt conveyors and fall on the ground in the form of a windrow perpendicular to the direction of movement of machine. The machine is operated at a speed of 2.5-3.5 km/h and has a field capacity of about 0.4 ha/h. The use of this machine for harvesting can save about 60-70% labour in comparison to manual harvesting.

Figure 3.34. 4-wheel tractor front-mounted vertical conveyer reaper cum windrower (Source: H.S. Sidhu)

Tractor rear mounted PTO operated self-raking reaper: The machine carries a cutter bar of 1.5m length, the drive to which is given from PTO of a tractor. It is a side delivery machine in which crop is collected over a platform and is delivered on one side in the form of bound bunches of desired size. The raking and sweeping of harvested crop is done mechanically. A profile cam controls raking motion. An index lever regulates the movement of cam rollers in such a way that either of first, second, third or fourth rake sweeps out the cut crop laid on the platform. The crop is tied into bundles of desired size manually. It can cover about 3 ha/day with field efficiency of 85%.

Tractor-rear mounted reaper binder: The machine consists of a cutting, gathering knotting mechanism mounted on a high pressure pipe frame with a 3-point linkage arrangement for hitching at the rear of a tractor. It has a 1.36m long cutter bar and power to various components is given from PTO through v-belts and pulleys. The machine can cover 1.5-2.0 ha/day at a forward speed of 2 km/h. Machine can be used for harvesting wheat and paddy both.

Self-propelled reaper binder: It is suitable for harvesting and making bundle of wheat, paddy and other oilseeds and pulse crops. It is operated by 9 kW diesel engines. The riding type self–propelled vertical conveyor reaper windrower is powered by a 9 kW, single cylinder, water cooled diesel engine having rated engine speed of 3000 rpm. It is provided with four pneumatic wheels; two driving wheels in the front having agricultural tread pattern tyres and two steering wheels at the rear having automotive tyres. Other systems include clutch, brakes, steering, hydraulics, and power transmission and an operator's seat is available to make the machine riding type. The harvesting system include crop row dividers, star wheels, standard cutter bar having 76.2 mm pitch of knife section, vertical conveyor belts and wire springs. The effective cutter bar width is 1.2 m. The crop row dividers enter the standing crop and the star wheels guide the crop towards the cutter bar and help in slightly lifting the crop after it is cut, and in turning it at right angle, prior to its conveying by the lugged conveyor belt. The two lugged flat belts convey the cut crop towards the centre of the machine and moves back on a platform where it makes a bundle of about 5 kg each. At the end, the crop is discharged on the ground in the rear. Working capacity of reaper binder is 0.3-0.4 ha/h. Weight of the machine is about 450 kg.

3.4.2 Threshers

Threshers are the most important component of farm mechanization. If threshing is not done timely, all efforts made by farmers and inputs given to crop goes wasted. The operation of detaching the grains from the ear head, cob or pod is called threshing. It is basically the removal of grains from the plant by striking, treading or rupturing. The traditional method of threshing using manual labour requires 150-230 man-h/ha. In various parts of Asia and Africa, threshing by smallholders is accomplished by treading the grains under the feet of animals, striking the grains with sticks, pegs or loops and removing the grains by rubbing between wooden rollers on a threshing floor or between the rasp bar and a concave of combine. Due to low output, the cost of operation is high and there is a huge loss of grains because of rodents, birds, insects, wind, and untimely rain and fire hazards. Power operated threshers overcome these difficulties to a great extent.

The threshing mechanism, which separates the grain from the stalks, consists mainly of a revolving cylinder and the concaves. A feeder beater is usually located in front of the cylinder and at the upper end of the elevator-feeder to assist the elevator-feeder in feeding the grain to the threshing mechanism. Most threshers are provided with the rasp-bar type cylinder and concaves. The grain is rubbed from the stems without materially cutting the straw. Tooth-type cylinder and concaves are available on some combines. Adjustments are provided for varying the speed of the cylinder to suit the kind of crop being harvested. V belt variable-speed drives are used on most combines. The straw is thrown back onto the separating mechanism, while the grain falls through the concaves onto a grain pan or grain carrier and is conveyed to the cleaning mechanism.

Harambha (High Capacity) Thresher for wheat

Haramba thresher is suitable for threshing wheat crop and is highly popular (Fig. 3.35). It is a basically a chaff-cutter type thresher. It consists of a threshing cylinder, concave, two aspirator blowers, reciprocating sieves, feeding chute, feeding conveyor, feed rollers, safety lever in the feeding chute and flywheel. Threshing cylinder has two chaff-cutter type blades and beaters. Chaff-cutter blades cut the crop into pieces and beater helps to detach grain from crop. Threshing material pass through the concave and light materials like chopped straw for use as fodder is blown away with aspirator blower while the heavier materials like grains, nodes etc. fall on a set of reciprocating sieves. The sieves clean the grain and there is an optional attachment of an auger to elevate the grains and conveys directly on to a trolley. Feeding of crop is manual by standing on a platform provided with the thresher. A safety lever provided in feeding chute prevents the entrapping of hands by the feed rollers. It is operated by PTO of a 35-hp tractor and is mounted on two pneumatic tyres for easy transportation. Capacity of the thresher varies from 1.5-2.0 t/h.

Paddy Threshers

Paddy thresher of pedal operated type consists of mainly a well-balanced cylinder with a series of wire loops fixed on wooden slates (Fig. 3.36). It has got gear drive mechanism to transmit power. While cylinder is kept in rotary motion at high speed, the paddy bundles of suitable sizes are applied to the teeth. The grains are separated by combining as well as by hammering action of threshing teeth. Paddy is threshed due to impact and rubbing action between threshing drawn loops and concave screen. The grains are cleaned with the help of a fan and cleaned grain goes down through the grain outlet at the bottom of the thresher. They are available in different horse power range. In a multi-crop thresher, threshed wheat crop passing through concave is cleaned by a set of sieves and a blower or aspirator. Axial flow of paddy crop is facilitated by the use of louvers provided on the upper concave.

Figure 3.35. Harmbha (high capacity) thresher for wheat

Axial Flow Paddy Thresher

The crop in this thresher is fed into the cylinder through a feeding chute located at one end of the threshing drum. The straw is thrown out of the threshing unit by paddles. The cleaning and separation of grain is accomplished by a set of sieves and a blower or aspirator. The paddy thresher has a axial flow beater type threshing cylinder. It consists of feeding hopper, threshing cylinder, concave, cylinder casing, two sieves and screen for cleaning and blowers/aspirators. The crop is fed into the hopper and it is received by the threshing cylinder tangentially and the moves along the cylinder axially. For cleaning purpose, the thresher has two aspirators, one blower and one thrower. Threshing efficiency varies from 97-99 %, cleaning efficiency varies from 90-97 % and cylinder loss varies from 0.7 to 3.6 %. It saves about 70% of labour and as compared to conventional method of manual threshing by beating.

Figure. 3.36. Axial flow paddy thresher

Maize Dehusker cum Sheller

This machine comprises of an axial threshing cylinder with a suitable concave and a thrower mechanism to eject empty stalk and husk. Grains fall on the cleaning sieves for cleaning. The thresher can thresh the dehusked maize cobs having moisture content in the range of 12-24 % successfully. The output capacity of the machine varies from 1200 -2400 kg/h. The threshing and cleaning efficiency of the thresher is in the range of 96-98 % and 94-98 %, respectively.

Groundnut Thresher

The machine can detach the groundnut pods from the vines. The capacity of the thresher is about 200 kg/h at moisture content of 35% (pods). Threshing efficiency is of the order of 99 % and cleaning efficiency varies from 94.2-97.0 % whereas the broken grain varies from 0.2-0.5%. There is a saving of about 83% in labour requirement as compared to traditional methods of threshing.

Sunflower Thresher

It consists of a threshing cylinder, concave, casing fitted with louvers, cleaning system, feeding hopper and frame. The cylinder concave clearance is 40 mm and is uniform throughout its length. The diameter of cylinder is 65 cm and length 150 cm. The first part of cylinder of length 133 cm has flat bars for crop threshing and the 2nd portion of length 17-cm has straw throwing blades. The cylinder casing is of hexagonal shape and is fitted with 7 louvers.

The louvers help the crop to move axially and the crop is rotated three and half times for complete separation of grains. The cleaning system has a blower and two sieves. The opening of top sieve is 16 mm and of lower sieve 6 mm. Recommended cylinder and blower speeds are 300-350 rpm and 1200-1400 rpm respectively. A tractor or 7.5 hp motor can operate machine. The machine has a capacity of 600-900 kg/h of clean grain. Threshing efficiency of the machine is 100 % whereas cleaning efficiency is about 90%. It saves about 70 % labour in comparison to traditional threshing.

Multi Crop Thresher

Since, farmers raise variety of crops as per the suitability of particular region, climate and soil conditions, thus there is a need to thresh all these crops for timelines of operation. Multi crop thresher can thresh crops like wheat, moong, paddy, grain, soybean etc. For these crop requirements are different, as in the case of wheat bruised straw is the main requirement. For pulses, seed damage should be minimal; as damaged seeds lower the quality and causes spoilage in storage. Commercially available spike tooth type thresher has been used for threshing moong and mash after incorporating few modifications. The threshing cylinder has 36 spikes placed six in each row. For threshing pulses, six spikes are retained on cylinder in six rows i.e. one in each row. The arrangement of spikes on cylinder periphery is axial. The output capacity is around 250 kg/h. The crop factors such as moisture content, grain size, condition of straw etc. influence the design consideration of main components of threshers. The farmer is primarily interested in end product, low cost, durable and reliable machine. The suitable multi crop threshers for cereals and pulses are commercially available in India.

Figure 3.37. A multicrop thresher

(Source: Dept of Farm Machinery and Power Engineering, PAU, Ludhiana)

A multi-crop thresher (Fig. 3.37) attains the axial movement of the crop while handling paddy and all crop material is made to move through the concave in case of wheat. The main components of multi-crop threshers are: feeding chute, threshing cylinder, aspirator blower, paddy chaff outlet, wheat straw outlet, hopper, and cam for oscillating sieves, oscillating sieves, transport wheel, frame, main pulley and louvers. The axial flow of material can be accomplished by providing seven louvers with spacing of 150 mm in the hexagonal casing. The clearance between louvers and tip of cylinder spikes is 20 mm. For wheat threshing, the first three louvers are placed with ribbed casing and side plates are fixed with top casing and concave to prevent material flow in the second portion. The direction of rotation of threshing cylinder is opposite for wheat than paddy. That is why; straw outlet of aspirator blower is repositioned. The top sieve has holes of 9-mm diameter for wheat and 5 mm for paddy grains. The lower sieve has holes of 1.5-mm diameter common for both the crops. The upper sieve can be changed easily depending upon crop to be threshed. The cylinder-concave clearance in the first section of threshing system (i.e. facing the feeding chute) has to be more while handling paddy than wheat. The machine output is 500 kg/h for wheat and 700 kg/h for paddy.

3.4.3 Grain and straw Combines

i. Grain combine

Combines are suitable for harvesting wheat and paddy and are of two types namely: self-propelled combine harvesters and tractor operated combines. Tractor operated combines can harvest 3-4 ha/day whereas self-propelled combines cover 5-6 ha/day. Machines are highly popular in NW India and there are large number of manufacturers of these machines. Self-propelled combine harvester with cutter bar table is expensive, but it is easily available from service providers at affordable rates.

The tractor operated combines require supporting tractors and trailers for transport to storage area. These machines are an important part of sustainable mechanization for smallholder farmers but they need to be linked to sustainable crop production intensification efforts in terms of the area under cultivation, the timeliness of operations, effective utilization of inputs and overall crop productivity (Fig. 3.38).

Figure 3.38. 4-wheel tractor-mounted driven combine harvester (Dasmesh Mechanical Works Pvt Ltd, Malerkotla, Punjab, India)

ii. Straw Combine

Straw combine is used to recover wheat straw after combine operation and is operated by a 35-40 hp tractor. Straw collected by straw combine is chopped into small size and collected in the trolley having a net to remove the dust. Also some grains are collected along with straw. The capacity of machine on an average is 0.5 ha/h and straw recovery is about 55-60%. Machine is highly popular.

iii. Super SMS for Combine Harvesters:

The manual spreading of loose straw in a combine harvested field takes 8-13 man-h/ha and it is very difficult to spread the entangled dry loose straw due to its light weight. Straw management system (SMS) known as super SMS was jointly developed by PAU Ludhiana and CIMMYT-BISA which can be used as an attachment in the rear of existing conventional combine harvester for chopping and evenly spreading the loose straw in the harvested area. Uniform spreading of the loose residue is a pre-requisite for successful use of the Turbo Happy Seeder (THS), to avoid choking and the creation of patches of thick deposits of residue which suppress crop establishment. This will not only facilitate the smooth operation of THS in combine harvested fields but also will help in uniformly conserving moisture in the field after harvesting which in turns is very helpful in widening the seeding window of wheat. Super SMS includes the stationary housing for attachment to the rear end of the combine harvester. The straw coming out of the straw walkers of the combine harvester is fed to the unit from one side and is discharged from the outlet of the housing (Fig. 3.39). Inside the housing, a rotor is mounted having six lugs in a row and four such equally spaced rows along the entire periphery of the rotor. The rotor operates at speed in a range of 1400-1500 rpm and driven through V-belt pulley arrangement. There are 24 stationary serrated blades fixed on the concave portion of the rotor housing. Each pair of flail during rotation passes over the stationary serrated blades and cuts the straw into pieces. The chopped straw is blown off tangentially and uniform spread is achieved with the help of deflector attached at its outlet. The deflector spreads the chopped straw into the full width of combine harvester. Additional cost of straw spreading with Super SMS combine harvester over manual spreading is around US $ 7 ha^{-1}. However, it resulted in the overall system saving of US $ 4 ha^{-1} when considering increase in field capacity of THS by 0.6 ha day^{-1}. The super SMS has an option of switching on or off using a small metal sheet. This enables the combine harvester with Super SMS attachment to be used as traditional combine harvester without dismantling the SMS attachment (for collection of residues from the field). Super SMS distributes harvested straw residues across a much wider swath, thus avoiding issues of rows of stubble residues forming into heaps in the harvested field and thus providing an even distribution of stubble residues. The straw coming out of the straw walkers of the combine harvester is fed to the unit from one side and is discharged from the outlet of the housing. The chopped material is blown off tangentially and deflected using a deflector for uniform spreading the residues in the entire width of combine harvester (Fig. 3.39). It can handle residue loads up to ~9 t/ha.

Figure 3.39. Super SMS while harvesting rice

iv. Precautions for Super SMS mounting on combine harvester

i. The rotating flail blades, bushes, plates and nut bolts of the rotor should be of exactly same dimensions, otherwise this may cause vibrations in the Super SMS unit. The Rotor of Super SMS should be dynamically balanced to minimize vibrations in the attachment as it works at 1600 to 1800 rpm.

ii. The Super SMS system should be supported from the combine chassis of combine harvester body to minimize overhang and vibrations.

iii. The overlap of the stationery blades and flails on the rotor can be adjusted by changing the angle and position of stationery blades assembly. The size of straw chop and load on the harvester is dependent on the overlap of the stationery blades and flails on the rotor. This overlap can be adjusted depending on the field conditions.

iv. V-belt and pulley section should be so selected that belt slippage is within acceptable limits.

v. The rotor rpm indicator may be attached with Super SMS as an additional safety feature.

vi. The end sheet of combine harvester may be modified to automatically open if the straw walkers of harvester clog during harvesting as an additional safety feature.

3.4.4 Paddy Straw Chopper

This machine chops the paddy straw left in the field after combine harvesting into small pieces and spreads the chopped straw evenly in the field. This straw then can be incorporated into the soil and subsequent drilling of wheat can be done. This is a enviournment friendly technology as farmers do not need to burn the paddy straw left in the field and also improves the soil health. Paddy straw chopper consists of a rotary shaft mounted with blades named as flails for harvesting and chopping the paddy straw. Two counter rows having serrated blades are mounted on the concave of front portion of straw bruising which further assists in chopping the straw. Field capacity of the machine is 0.3 ha/h and approx. 70 % straw is chopped in the size less than 10 cm. (*Source: Dept of Farm Machinery and Power Engineering, PAU, Ludhiana*)

3.5 Calibration of Seeders, Planters and Sprayer Machinery: Basic Principles and Steps

One role of agricultural machines is the dispensing of materials such as seeds, fertilizers, and spray solutions. These machines are designed to provide the material at a fixed, or variable rate, and in a fixed, or variable pattern. Accurate calibration of machinery is frequently neglected by many farmers but the use of accurate quantities and correct placement of seed, fertiliser, or herbicide is essential for producing a good crop to achieve economic success. Excessive use of such a product adds to cost and can even reduce yield, while inadequate use will reduce yield, or simply fail to have the desired effect. Therefore, accurate calibration of machinery is very essential in agricultural production. Planting success begins with proper equipment maintenance and calibration. Anyone proposing to offer a hire service using the equipment will need to gain experience in the field operation, maintenance and servicing of all of the items. Farmers and service providers must apply the correct and uniform amount of seed, fertilizer and pesticide or herbicide per hectare at the required spacing. To achieve this, it is necessary to calibrate planters and sprayers. In addition, calibration skills will be needed for planters, seeders and sprayers. The calibration of sprayers, planters and seeders all require careful calibration each season for applying the correct amount of a relevant product. This is necessary because not only do products change in size and/or consistency each year, but machinery wears out slowly and may need a change in the amount of the product used from season to season even when using the same product through the same machine.

A planter/drill is a farm implement that sows (plants)seeds in rows throughout a field. It is connected to the tractor with a drawbar or a three-point hitch. Traditionally, a seed drill consists of a hopper filled with seeds arranged above a series of tubes that can be set at selected distances from each other to allow optimum growth of the resulting plants.Term planters is applied to machines designed to drop discrete numbers of seeds (such as maize) at specified distances; seeders sow a continuous flow of smaller seeds, such as cereals. The biggest difference between a drill and a planter is the row spacing. A planter is usually adjustable for row spacings of between 50 cm to 100 cm, and is used for row crops like maize and soybeans. A drill has much closer row spacings, around 15 to 20 cm, and used to plant small grains like wheat. Sowing of seeds with a seed drill is better than any other method because it positions the seeds precisely at equal distances and proper depth. It also ensures the cover of seeds by soil which saves them from birds.

Seed drill performs the following functions:

1. Metering of pre-determined amount of seed (seed norm)
2. Opening a seed furrow to the proper depth.
3. Planting the seed in the furrow in specific manner.
4. Covering the seed with the soil.

3.5.1 Calibration of Seed Drill

The procedure of testing the seed drill for correct seed rate is called calibration of seed drill. It is necessary to calibrate the seed drill before putting it in actual use to find the desired seed rate. It is done to get the pre-determined seed rate of the machine. First, check for seed depth. As soil conditions change with different locations, it is important that operators check seed placement behind the planter for depth, spacing, and seed-to-soil contact. Second, knowing the optimum rate is critical in achieving potential yield. Third, inspect the seed opener and adjust as necessary. Although you may have correctly set the depth adjustment, depth wheels may not be firmly in contact with the soil surface and the planter unit may be riding up on the seed opener. Additional down-pressure or weight may be necessary in firm soil conditions for the seed opener to penetrate to desired planting depth. Finally, look at cover disc and pack wheel tension. Seed-to-soil contact is usually controlled by coverage and compaction of press wheels and covering discs. Many planters have an adjustable down-pressure spring to vary the amount of surface pressure and coverage for supplying adequate soil contact. Spring pressure may need to be increased in drier surface soil for adequate soil contact and to help bring moisture up to the seed.

Calibration is a trial-and-error process. The seed is collected from the simulated seeding of a fraction of an acre, weighed, and compared to the desired seeding rate. Planting drills must be calibrated to ensure the proper seeding rate of small seeded crops. With the high seed cost of new varieties, planting rate accuracy is an economically important task. The meter setting chart provided by the machine manufacturer may or may not be accurate for small-seeded crops, depending on drill wear or condition. Even new machines set at the recommended seed meter setting may not be precise enough to deliver the proper seeding rates of small-seeded legumes or cereals. It is important to check drill seeder components to be sure parts are working properly, especially on rental machines. In rental drills, it is not uncommon to find obstructions in seed tubes such as spider webs or old seed from a previous use. Check all seed tubes to make sure they are clear and allow seed to drop through. Various methods may be used for planter calibration, but two factors must be known – the area covered and the amount of seed used. This guide will cover basic methods for calibrating drill and broadcast seeders. Calibrate the drill before entering the field. Some no-till drills have a single control meter for adjusting the seed flow from the seed box. Others have two control meters, one for each side of the seed box. In that case, the seed flow must be checked for both sides of the seed box. All seed tubes should be checked for obstructions before each use to avoid skipped rows resulting from plugged tubes. The following steps are followed for calibration of seed drill.

1. Raise drill off ground so that the ground wheels turn freely. Make a mark on the drive wheel and a corresponding mark at a convenient place on the body of the drill to help in counting the revolutions of the ground wheel.
2. Measure circumference of drive wheel and determine drill width.
3. Calculate the number of rounds of the drive wheel needed for one acre (4000 m^2) or one ha (determine the circumference of drive wheel to calculate total number of rounds to cover the known area).
4. Fill the selected seed in the seed hopper. Place a container/plastic bag under each boot/tube for collecting the seeds dropped from the hopper. Check each tube for obstructions to ensure proper seed flow.
5. Mark a reference point on the drive wheel with tape or chalk, engage the clutch and rotate the ground wheel for N = 10000/P x D x W, revolutions per minute. Collect the seed in container while turning the drive wheel.
6. When the drive wheel has been turned the proper number of turns, combine the seed from each container and weigh the seed.
7. Calculate the seed rate in kg/ha (see calculations below). If the calculated seed rate is higher or lower than the desired rate of selected crop, repeat the process by adjusting the seed rate control adjustment till the desired seed rate is obtained.

Use the following equations to determine seeding rate at the setting used.

a. Determine the working width (W) of seed drill: W= (M x S), Where, M =Number of furrow openers, and S = Spacing between the openers, m

b. Find the length of the strip (L) having working width (W).

Suppose we have 1 ha of area (=10000 m^2)
L*W= 10000 m^2
L= 10000/W, meter

c. Determine the number of revolutions (N) of the ground wheel of the seed drill required to cover the length of the strip (L) =P x D x N = 10000/W

N=10000/P x D x W revolutions per minute

Calculate seeding rate.

Seeding rate (S) (kg per ha) = A x T x10,000 / (N x D x W).

Where A = seed from one seeding tube T = total no of tubes on machine N = no of collection tubes D = distance in 50 revs meter drive wheel W = width machine

Example • 1500 gm seed was collected from five seed tubes • 20 seed tubes on machine • 50 revs of meter wheel measured 25 meters in distance • Machine is four meters wide. Therefore, Seeding rate (S) (kg per ha) = 1500 x 5 x 10/ (50 x 25 x 4) =15kg /ha

Checking seeding depth

Calibrating the drill for seeding rate is important, but proper seeding depth is also critical for small-seeded crops. Planting seed too deeply is the cause of many planting failures each year. Small-seeded crops as well as direct seeded rice should be planted at a depth of about 2-3 cm or less. Planting small seeds deeper can result in poor emergence and poor stands. After calibrating the drill, plant test strips to determine the depth at which seed is being planted. In case of small-seeded, a small amount of seed can be spray painted bright orange and allowed to dry thoroughly, mixed with plain seed and placed in the drill seed box immediately above each seed outlet. The colored seed is easily seen in the row. Once seed placement depth has been determined, the machine can be adjusted as needed according to the manufacturer's instructions.

3.5.2 Calibration of Planters

For large seeds (e.g. maize and beans), it is always advisable to use pre-graded seed; however, if the farmer's own seed is used, a uniform sample can be obtained by adopting a system of three sieves. The top sieve retains over-sized seeds, while the bottom sieve allows the passage of under-sized seeds: the selected size collects in the middle sieve. If graded seed is not used, it is not possible to assure the uniformity of the seed rate, and there may be an increased risk of seeds jamming and breaking. This is especially important for planters with horizontal rotating seed plates.

The method of calibration for planter is nearly similar to for seeder. The planter can be tested either under field condition or in the workshop. Before calibration it is essential to know the numbers of seeds per hill, the distance between hills and rows and fertilizer rates per hectare. In the case of animal- or tractor-drawn planters, the drive wheel circumference is measured, jacked up and rotated manually for a counted number of revolutions (say 10) (this procedure is repeated for the range of seed rate settings provided on the machine). The seeds are collected in a suitable container placed under the seed-delivery tube (this could be a plastic bag attached to the outlet). The distance between seeds along the row can then be calculated as follows:

Distance between seeds (cm) =
Circumfernce of drive wheel
(m) × No. of turns × 100 cm/m divided by No. of seeds dropped.

For field calibration of planter, fill hoppers and plant several meters. measure 1 meter along each row. count the number of seeds in one m along each row. Calculate average number of seeds per row and multiply average number by appropriate factor. For calibration of hydraulic planter leave planter in transport mode. Place a collection container under rows and turn on drive for a set distance. Count the seeds collected

Calibration of a single-row no-till planter: The drive wheel is turned by hand and the seeds collected in a plastic bag attached to the seed outlet. Seeds can be counted and/or weighed to calculate seeding rates per ha. From here, it is simple to calculate the planting rate per ha when the distance between crop rows is factored in. Furthermore, if the seeds are weighed, then the weight of seed sown per ha can be easily calculated.

Calibration of seeders and fertilizer distributors: This is a similar procedure to that outlined for planters, except in this case, the output of seed and fertilizer is weighed, and the application rates per hectare (kg/ha) calculated. There will usually be a range of adjustments for both seed and fertilizer rates, and the calibration procedure should be repeated for specific crop and fertilizer categories over the full range of calibration settings. The actual calibration is not difficult once you have selected the required rate, which will depend on the eventual plant population required. Row to row and seed to seed distance has to be set. Raise the metering wheel and rotate for (say) 10 revolutions. Collect the seed delivered in a suitable container. The seed and fertilizer metering mechanisms on the planters are usually operated by a ground-drive wheel and the procedure for calibration is as follows:

1. Measure diameter (D) of ground wheel
2. Calculate perimeter/circumference (P) = π x D (=distance covered on ground)
3. Number of revolutions made by planting disc/roller etc. per revolution of ground wheel = N (say)
4. Number of cells/spoon groves on disc = C (say)
5. Therefore, distance between seed to seed =$\pi D/NC$

   N can be varied with having a gear train.

   C can be of different sizes for different crops and different varieties.

   N=No. of revolutions of plate

   No. of revolutions of ground wheel

The metered amount can be weighed and the application rate per hectare calculated as follows:

Seed rate = Weight of seed delivered (kg) × 10 000 (kg/ha)/ P (m) × No. of revolutions of ground wheel × row spacing (m)

Repeat the calibration at least three times for each transmission setting. Follow the same procedure to calculate fertilizer application rates per hectare.

Fertiliser Calibration : Remember that the fertilizer drill width will vary with bare ground and crop height. It is important to measure the effective width as large particles will spread out farther than small particles. There is a need to allow for overlap. Fertiliser boxes are fitted to row crop planters. Follow the same steps as outlined for calibration of seeders. as follows:

Steps involved in field calibration are as under:

1. Place some of the fertiliser in the box.
2. Remove fertiliser placement tubes from their boot and tie bags over the tube outlets in such a way as to collect any fertiliser which would go down the tube.
3. With the fertiliser box drive mechanism engaged, drive the machine over a measured distance (D, metres) with a minimum distance of 100 m.
4. Remove the bags and weigh the total amount collected (kg).
5. Measure the total width covered by the fertiliser box in metres

Example: If 3 kg were collected from a 2-m fertilizer cum seed drill over 100 m, the appropriate fertiliser rate would be = 100 x 3/2 = 150 kg/ha

Or, Weight of fertilizer delivered (kg) × 10,000 divided by distance travelled (m) x row spacing (m)

6. Change the lever adjustment and repeat the steps 1-5 until exact fertilizer rate is obtained.

Calibration of Fertilizer Spreader

Information provided by spreader manufacturers on the settings required to apply a selected quantity of fertiliser is generally fairly accurate - at very least, it is a good starting point. To check this rate, place a known quantity of fertiliser in the spreader and measure the area that it covers evenly. Divide the quantity used by the area (ha) covered to obtain the rate applied/ha. If alterations are required, adjust the settings and repeat the above exercise on another section of the paddock.

Calibration of sprayers

Sprayers should always be tested before use for: correct operating pressure, nozzle overlap, individual volume/time discharge (calibrated for application volume). Thoroughly clean all the screens and sprays nozzles. This will help insure proper operation. All the nozzles should be of same size and quality. Fill the tank half full of water and do not empty it after. See that the spray patterns from all nozzles are the same and consistent with what we need. Replace any nozzles that lack uniform spray patterns. First, a quick check on throttle speed—you can't always trust your tachometer. Travel speed is a critical factor in maintaining accurate application rates. Incorrect settings can skew spray rates. Bear in mind that a one-second error in timing could result in a 5% application error. Check the operating pressure you will use for spraying. Adjust to that pressure while the pump is operating at normal speed. Be sure water is flowing through the nozzles. Do not change the pressure when you actually spray.

3.6 Operation and Maintenance of Agricultural Machinery: Basic Guidelines

Agricultural machinery maintenance is a vital aspect of successful agricultural operation and production. Operating farm implements and machines is associated with risks of accidents and health hazards. Consequently, measures must be taken to eliminate these risks. To give long and faithful service, farm machinery needs not only to be operated correctly, but maintained and serviced at the intervals indicated in the operators' manual. Training courses do not always find the time to discuss these issues in the detail required. Whilst routine maintenance (lubrication, chain tension, tyre pressure, cleaning out fertilizer residues, etc.) are wholly the responsibility of the machine operator, servicing (for example of engines and transmissions) is not. Correct operation and regular maintenance are essential for smooth running of the hire service business. When a new machine is delivered, the customer should insist that the supplier provide full instructions on its operation. In addition to a comprehensive operator's manual, the customer should also receive a maintenance manual and, if possible, a spare parts manual. The operator must become familiar with the operating instructions and "respect" the machine. Never underestimate the value of a good operator. The owner needs to be aware of the guarantee period and of any obligations under the guarantee.

Maintenance can be defined as the practice of keeping in form or shape of equipment or machine system in its original status as much as possible. The high cost of machinery demands proper maintenance aiming at increasing service life and reliability of any machine in performing its desired function. Proper maintenance of machines will help in longer working life, higher resale value, lesser breakdown, and lower fuel and oil consumption. A system for periodic service and maintenance is essential for agricultural machines is important so as to prevent unnecessary wear out of parts, and keep time loss due to breakdown to a minimum. Therefore, it is important to follow maintenance schedule for all machines including tractor as provided by the manufacturers. It is also advisable to have a notebook for every machine and implement in which important data concerning service dates, changes of oil, repairs, etc., can be written down. From the database it is easy to get an overview of the status for all machines; service, maintenance, repairs, and cost.

Monitoring is a maintenance technique of the machine that predicts problems by monitoring changes in variables such as pressure, temperature, flow rate, electrical power consumption, capacity and structural components features of agricultural machinery (such as blade angle in tillage implements, tines angle and rotor speed in harvesting machinery, nozzle type and pump performance in agricultural sprayers) can also be used for an assessment of agricultural machinery condition and for the early detection of faults. Corrosion monitoring helps provide an indication of the extent of corrosion, the corrosion rate and the corrosion state (e.g., active or passive corrosion state) of material. Temperature measurement helps detect potential failures related to a temperature change in equipment. Measured temperature changes can indicate problems such as excessive mechanical friction, degraded heat transfer and poor electrical connections. Dynamic monitoring involves measuring and analyzing energy emitted from mechanical equipment in the form of waves such as vibration, pulses and acoustic effects.

Measured changes in the vibration characteristics from equipment can indicate problems such as wear, imbalance, misalignment and damage. This chapter provides guidelines to agricultural machinery maintenance and operations.

Operation of Tractor

Operational efficiency and safety should always be paramount in a tractor operator's mind. Most accidents occur because operators have not attached the equipment correctly, travel too fast or under estimate side slopes when operating on undulating country**.** For details of procedures for specific equipment, always refer to the operator's manual. When operating a tractor, the following procedure should be followed:

1. Check the tractor and implement before going to the field. Ensure that the implement is securely hitched. Fit attachments according to the manufacturer's instructions. Always attach implements to the draw bar or the mounting points provided by the manufacturer. Never alter, modify or raise the height of the draw bar unless provided for by the manufacturer. Regularly check safety pins on towed lift-wing implements, to ensure they are not worn. Ensure all guards on towed implements are in place before operating. Never hitch above the centerline of the rear axle, around the axle housing or to the top link pin. When parking, always lower the three-point linkage and towed implement.

2. Upon reaching the work area, check if the field conditions are suitable for the assigned task. At the field, unlock the brake pedals so wheels can brake separately for improved turning ability. Do not change gears when the tractor is moving.

3. Never attach implements unless the PTO shaft is guarded. When operating a 4-wheel drive tractor engage the front drive in the field. Do not drive on the highway with all 4 wheels driving as this may cause "wind up" which could damage the transmission. Select the operating gear. In a dry work situation, a good starting gear is normally 3rd low or 1st high.

4. Set the throttle to mid-range using the hand throttle and slowly release the clutch. At the same time lower the implement into the soil. Then increase throttle setting to full throttle using the hand throttle control. Foot throttles should only be used for transport situations.

5. If the implement is operating at the desired depth and the engine cannot hold its engine rpm then select a lower gear.

6. Stop the tractor properly before any intervention. Remove the key from and lock switches on static equipment.

7. Follow the manufacturer's instructions/ procedures. When the job is finished, always replace the guards before restarting the machine.

8. Do not remove guards unless the power to the machine is locked off or the key removed. Replace all guards before making a test run or restarting the machine.

Indicators of Efficient Tractor Operation

When a tractor and implement are properly matched, the tractor should be using 70-80% of its maximum power. The indicators of efficient tractor operation are rpm, smoke, fuel consumption, wheel slip and tyre wear. If the full throttle unloaded engine speed is 2500 rpm, then the loaded speed should not drop below 2300 rpm. If the engine speed drops by more than 200 rpm select a lower gear or lighten the load. Whilst excessive black or blue smoke coming from the exhaust is not always indicative of overloading, in general the load should be reduced. If this situation arises continuously then the tractor checked for excessive oil or fuel usage. The fuel usage of a well maintained and operated engine can be easily calculated. Fuel consumption should not exceed the rated engine power. Levels for all wheel tractors operating in the normal conditions should fall in the range of 8-15%. In wet paddy situation obviously, these figures will be higher and wheel slip is often used for puddling the soil when cage wheels are fitted. The excessive tire wear especially on front wheel assist tractors may indicate poor set up and operation. Tire wear is increased when tire pressures are not set correctly.

Maintenance Checks Before Starting the Tractor Engine

A maintenance check should always be undertaken before starting a tractor or machine.

The most common controls and safety levers used when operating a agricultural tractor are:Stop button or key, Brakes, Clutch pedal. Throttle (hand and foot throttle); Gear Levers.

Light switches and warning lights. Power-take-off lever (PTO). This lever activates the tractors PTO shaft, which is used to power the equipment attached to tractor like tillers, and pumps. Front wheel engagement lever or button. Draft control lever – Position or height control lever; External hydraulic control valve. Drop valve- excessive speed of the drop may cause damage or injury. Adjust the speed of drop slow enough for safe operation. Differential lock –It is used to lock the differential when the tractor drive wheels begins to slip and the machine bogs down. It makes both rear wheels rotate at the same time and helps forward propulsion.

A simple way to conduct a systematic check of the different systems on a tractor is to remember is **WOGAM.** These initials stand for Water, Oil, Grease, Air and Miscellaneous. Check the oil, water and fuel level and air cleaner condition. Check the coolant level in the radiator. Do not remove radiator cap unless the engine is cool. To check before removing the radiator cap, squeeze the radiator hose. If the hose can be easily squeezed this means that the system is not pressurized and it should be safe to remove the radiator cap. If the engine is hot turn the cap slowly to the “first stop” position and release the pressure before removing the cap. Both engine oil and the hydraulic oil level should also be checked via the dip stick. Lubricate standard tractor grease fittings regularly, especially when using the tractor in extremely wet and muddy or dusty conditions. Check tires daily for damage or low pressure. The radiator grill and must be kept screen clean. This prevents the engine from overheating and allows good air intake for the air cleaner. Also, check wheel nuts, cowlings and look for loose nuts and bolts and improper or poor implement connections. Make sure all implements are securely fastened with proper clips and pins and safety cowlings are in place especially when using PTO driven and 3-point linkage driven equipment. As engines operate, they lose power and fuel efficiency. To obtain the optimum performance from an engine, the power produced and the fuel consumed should be checked. The tractor should be tested on a certified PTO dynamometer found at most equipment dealers and check to see if it produces rated PTO horsepower. If tractor power is down by more than 5%, adjustments or a tune-up is needed. A tune-up may include changing air and fuel filters, cleaning and adjusting injector nozzles, and adjusting engine timing. Another important part of tractor operation is checking fuel efficiency.

Maintenance of Machinery

All of the machines owned by a hire service business should have a maintenance schedule. All machines wear out. How quickly they wear out depends on how well they are operated and how well regular preventative maintenance is carried out. Carrying out regular maintenance costs money. However, the investment pays for itself many times over. A machine kept in good working order costs less to operate and there are fewer breakdowns and lower overall repair costs. Moreover, when one part fails on a machine, other associated parts may also be damaged: the owner not only has to repair the immediate breakage but also the associated damage. Breakdowns increase the risk of failing to deliver required services, resulting in financial losses for the business and tarnishing the image of the service provider. Badly maintained machines lead to accidents and higher costs.

The costs of maintaining machines include oil, spare parts, shelters, and construction and maintenance of a workshop. Fixed maintenance costs refer, for example, to shelters, while variable costs refer, for example, to spare parts and lubricants. It is essential to keep accurate records of maintenance costs so that the hire service can have a better understanding of the real costs of a machine.

Traditionally, maintenance is performed in either time based fixed intervals, called preventive maintenance, or by corrective maintenance. With the preventive approach, maintenance is performed in order to prevent equipment breakdown. With the corrective approach, maintenance is performed after a breakdown or an obvious fault has occurred. For some equipment and faults, corrective maintenance action must be performed immediately, for others the maintenance action can be deferred in time, all depending on the equipment’s function.

Timely preventative maintenance and inspection will not only help reduce major problems and downtime, it will also help identify problems when they can be corrected with relatively minor repairs. Equipment repaired during the off season can save money on service at mechanics' shops. An effective machinery service program requires good record keeping. The maintenance program must be based on fact as determined by an accurate service record for each piece of equipment as recommended by the operator's manual and adjusted to individual conditions. Effort spent in this area of farm management is more than repaid by consistent, reliable operation of machinery, reduced fuel bills and extended equipment life.

The maintenance on machinery and its implements, equipment and farm vehicles includes tasks such as maintenance of electrical connections; replacing or repairing safety guards; sharpening or replacing machines' cutting blades; regular maintenance of engines, cooling systems; lubrication, oil changes, filter changes; air pressure in tyres; cleaning and lubricating power-take-off shaft guarding; maintenance of hydraulic systems; and cleaning, lubricating, replacing broken and used parts. Servicing is needed for the fuel system, air intake system, changing engine crankcase oil, cooling system, electrical system and clutch and transmission.

Objectives of Good Maintenance Practices

Good maintenance practices are essential for efficient operation of all types of machinery. Efforts spent in this area of farm management is more than repaid by consistent and reliable operation of machinery, reduced fuel consumption and bills, extended equipment life among others. Maintenance of farm machinery is complicated by the usage pattern of short spells of intense activity, followed by periods of non-use or storage. The basic objectives of good maintenance practice include: (i). To intervene before failure occurs, (ii). To do maintenance only when necessary, (iii). To reduce number of failure and shutdowns, (iv). 4. To reduce maintenance cost and cost due to production lost, and (v). Increase life of equipment.

Preventive Maintenance

The objective behind preventive maintenance is to either repair or replace components before they fail. Preventive maintenance is a planned maintenance of machinery resulting from periodic inspection in order to minimize the breakdowns and depreciation rates. The preventive maintenance includes periodic (predetermined) and condition-based maintenance (CBM, diagnostic maintenance). The CBM can have dynamic or on request intervals while the periodic maintenance is scheduled in time. Preventative maintenance reduces the risk of machine failure and costly repairs. To invest time in the maintenance of farm machinery is very cost-effective. Good maintenance begins with good operation. Regular maintenance is one of the prerequisites for a long living and reliable engine performance.

In general, preventive maintenance activities include inspection, servicing (cleaning, lubrication, adjustment, alignment, and/or replacement of sub-systems and sub-components that are fatigued). The preventative maintenance programme begins after the machinery is placed into full operation. This program should include regular inspection set up on a periodic basis, after a specified number of operating cycles, or a certain number of operating hours. These intervals are established based on manufacturers' recommendations. Additional servicing is often necessary and depends on the type of operation the engine is subjected to. Mistakes made due to lack of skill or knowledge are often more expensive than employing a reputable mechanic.

Routine maintenance is the simplest form of planned maintenance but very essential. As the name, it is carried out at regular intervals. It involves periodic check of relevant areas. The frequency of such checks range between hourly, daily, weekly and monthly or as recommend by the manufacturers. Routine maintenance reduces fuel bills and extends equipment life. Examples are washing and cleaning, filing of distributor cap, change of oil, topping of battery electrolyte, lubrication, inspection and minor adjustments of pressure, flow, tightness etc.

CBM has been defined as maintenance actions based on actual condition obtained from in-situ measurement. The CBM can have dynamic or on request intervals while the periodic maintenance is scheduled in time. The main point being that the machinery condition is assessed under operation with the intention of making decisions to whether it is in need of maintenance or not and if so at what time does the maintenance actions needed to be executed and not to suffer a breakdown or malfunction. No two pieces of equipment have the same preventive maintenance needs. Each machine has different imperfections and is used under different conditions. Some equipment can safely run two or three times longer than recommended intervals.

Corrective Maintenance

This is the aspect of maintenance, which is necessary to put machine and equipment in good working condition immediately to avoid serious consequences. For instance, cleaning of distributor cap in the electrical system of an engine. The machine can still function but when not attended to, can cause major breakdown in the system. The following suggestions for machinery maintenance are worthy of consideration. Follow manufacturers' instructions for all settings, adjustments, maintenance instructions, operating requirements and long-term storage. Also follow manufacturers' recommendations on safety aspects of operation and repair. Do not overload equipment, or operate at higher speeds than manufacturer recommends. Keep all cutting edges sharp and clean because sharp cutters require less power and reduce overall load on equipment. Replace these items at end of season rather than at season commencement. Inspect machinery at end of season or harvest. Repair and adjust as required. Store equipment in clean and dry conditions. Remove all vegetation such as grass and crop residue from equipment before storage periods to avoid corrosion to metal surfaces. It is important to wash the machines and inspect that any damage, leaks, etc., which need to be repaired for the next season.

Repair and Maintenance of Tractors

Tractors are often the most expensive, sophisticated and potentially dangerous piece of equipment used on a farm. Always match the power units to the size and type of machines, so that all field operations carried out on time with a minimum cost. If the tractor is oversize for implement, the running costs will be high. If the implements are too large for the tractor, the quality and quantity of work may be less or the tractor will be overloaded causing excessive breakdown. Tractor operators need to perform basic maintenance checks and be familiar with the location and understand the operation of each control lever or button on the tractor before attempting to use the machine. Regular maintenance checks will help to keep the machine in good working order and prevent unnecessary breakdowns at critical times. Care needs to be taken at all times when using a machine to prevent unnecessary damage to the machine, the operator and surrounding environment. Regular inspection and service of tractors is important to ensure continuity of farm work and to prevent accidents in the field and in the work shop. Day-to-day maintenance of tractor includes oil and filter changes, battery charging and replacement. Before working with any machinery, operator should carry out a basic check to make sure that the machinery is in good working order. Check for mechanical defects (paying particular attention to brakes).

The maintenance issues for 4WTs apply also to 2WTs. The forward-mounted diesel engine of a 2WT drives the transmission via a V-belt and pulley system. The gearbox drives the wheels through dog clutches, which are used to steer the tractor in work. If a rotary tiller is attached, it is activated by a separate gear lever and the rotary cultivator shaft is driven by a chain and sprocket transmission. Do not engage the rotary cultivator when the tractor reverse gear selected. Never attempt maintenance adjustments on the tractor with the engine running. Keep all guards in place and avoid loose clothing that could catch in moving parts. Always keep the transmission in gear and never attempt to change gear on the move. Stay clear of the hot exhaust pipe or radiator. Make sure that the gear lever is in neutral before cranking the engine. Never attempt sudden turns with the steering clutches at high forward speed; slow down first. Read, understand and pay strict attention to the safety messages in the operator's manual and heed warnings attached to the tractors and adhere to the recommended maintenance schedule.

Safe use of Tillage Equipment

An operator must have an understanding of the function, operation and limitations of the equipment he/she is operating and the operator must resist the temptation to be hurried into an accident. Lower the plough to the ground or install hydraulic cylinder locks when the plow is not in use. Secure the machine in the raised position by installing safety locks or hold-up pins when servicing or cleaning it. Never grease, oil, or adjust the tiller while it is in operation. Escaping hydraulic oil under pressure can cause serious personal injury and infection. Therefore, be sure all connections are tight and that oil lines are undamaged. Always relieve hydraulic pressure in lines before disconnecting hoses. Never depend on tractor hydraulic pressure to carry harrow weight in transport--use safety lock, and relieve pressure in cylinders. Lock the tractor drawbar in fixed position when transporting wheeled disks. Lower the machine or install safety lock when storing a disk harrow. Never inspect hydraulic hoses with your hands because a fine jet of hydraulic fluid can pierce the skin. Use a piece of cardboard to test the hose for leaks. Make certain the hydraulic pump is turned off. Lower the attached equipment to the ground and confirm that load pressure is off the system. Following manufacturer's guidelines and working cautiously will help to produce a safer working environment for everyone.

Maintenance of Planters

Proper servicing can mean difference between profitable crop and high losses. planters are precision instruments they require large amounts of care. Clean planter thoroughly. Check for obstructions to keep the mechanisms operating properly. Inspect metering systems for worn or broken parts and repair or replace any damaged parts. Check all bolts and hoses for tightness. Lubricate at appropriate times and use correct type of lubricant. Bearings are very important machine element. The maintenance has great importance for the function and the lifetime of the bearings. The bearings must always be supplied with clean lubricants. Frequent inspection of the bearings is recommended. If the sound from a bearing is suspicious or the bearing is too warm when running, it is better to change the bearing to avoid a breakdown. Change the wearing parts (shares or tines) of the implements, for instance ploughs, harrows, etc. to keep the implement functioning properly.

Avoid getting dirt into bearings and wipe of fittings before lubricating. Empty and clean all boxes and check for worn or broken parts and replace them before next season. Coat furrow openers, knife and disk covers with protective coverings. Paint any exposed metal surfaces and lubricate all bearings. Store inside away from weather when not in use.

Maintenance of sprayers

Ensure that the equipment is in good working condition (no leaks or blockages). Check that the valves and switches are working properly and that the spray nozzles and filters are not worn or clogged. Replace worn-out or defective parts immediately. Clean the equipment immediately after use. Lubricate moving parts as indicated in the operator's manual. Regularly check for, and tighten, any loose bolts and nuts.

To prevent clogging of nozzles strainers having fine mesh screens are preferred. Before starting spraying, nozzle tip, strainer and nozzle body should be thoroughly rinsed with water. Never use pin/wire to remove particles from the spray tip because it will damage the spray tip. To have uniform herbicide spray pattern it is advisable to remove worn out and damaged spray tip.

Storing farm Equipment Properly

Machines, including tractors, combines, planters, drills, should be kept inside. Before storage equipment can save you time when you need it most during busy seasons and can reduce the expense of repairs. After use and before they are stored until the next season, they ought to be carefully cleaned. This is especially important for combines and other complex machines. Most valuable and vulnerable machinery kept out of the weather can save a lot of money. Proper storage also saves money by reducing repairs and time in the shop. Parts such as belts, tires and hoses deteriorate rapidly when unprotected. Usually, the deterioration that occurs to the tires and bearings is less than the cost of providing building space. Inspect machinery at end of season or harvest. Repair and adjust as required. A good time to carry out general lubrication, oil changes and filter changes is at the end of seasonal operations. First quality fresh oils and lubricants at this stage provide the best protection for metal surfaces during storage periods. Engines and hydraulic systems should be thoroughly warmed up periodically during periods of non-usage. Cooling systems are frequently overlooked.

Conclusion

The level of execution of the routine technical maintenance and repairs is one of the most important factors having the essential influence on the process of machines, tractors and agricultural transport means wear. The breakdowns of agricultural machines often interrupt the technological process. The time of machine repair during intensive works in farm is a crucial element in the quality of their realization. The factors which have a decisive influence on the maintenance and repairs are the workshops equipment of technical facilities with modern tools and devices, as well as the technical level and the qualifications of repair staff. A retailer or small manufacturer has to have access to supplies from a wholesaler; large-scale manufacturers will need regular access to supplies and other inputs. The fundamental requirement for a sustainable sub-sector is a strong linkage between these different parties and that all of them must be able to make a livelihood from their businesses. Otherwise, there will be a total collapse. The main objective of defining a mechanization strategy is to establish conditions which will ensure the free and undistorted development and operation of these linkages and the definition of actions which will allow this to happen.

Suggested reading material

Anonymous (2019). Machinery calibration: boom-sprays, seeders and fertiliser applicators department of primary industry and resources AGNOTE No: C31. last updated: February 2019 P. 6. (HYPERLINK "http://www.dpir.nt.gov.au" www.dpir.nt.gov.au).

Ekstrom, D. (2019). Farm equipment repair and maintenance. Machinery Calibration: Boom-sprays, Seeders and Fertiliser Applicators Department of Primary Industry And Resources Agnote No: C31 last updated: February 2019 Pages 6. (www.dpir.nt.gov.au). Details of the procedures can be found in FAO's technical bulletin on testing agricultural machinery.

FAO (1994). Testing and Evaluation of Agricultural Machinery and Equipment: Principles and Practices; Agricultural Services Bulletin 110; Food and Agriculture Organization of the United Nations: Rome, Italy, 1994; p. 272, ISBN 92-5-103458-3.

Kirui, A.K. and von Braun, J. (2018). Mechanization in African Agriculture. Working paper No. 169. ZEF Working Paper Series, ISSN 1864-6638 Center for Development Research, University of Bonn, Germany.

Norén O. (2009). Agricultural mechanization and automation – Vol. I - Maintaining Working Conditions and Operation of Machinery. ©Encyclopedia of Life Support Systems (EOLSS) maintaining working conditions and operation of machinery. Swedish Institute of Agricultural Engineering, Uppsala, Sweden.

Segun R. and Bello, S. (2008). A Guide to Agricultural Machinery Maintenance, and Operation. Farm Machinery Repairs and Maintenance A Practical Manual. Fasmen Communications, 79/94 Owerri Road, Okigwe, Imo State – Nigeria.

Sustainet, E.A. (2010). Technical Manual for farmers and Field Extension Service Providers: Conservation Agriculture. Sustainable Agriculture Information Initiative, Nairobi.

4 Crop Management in Conservation Agriculture: Principles and Practices

4.1 Crop Establishment

There are basically 3 types of seedbeds: flat beds, raised beds (fresh, permanent and raised-sunken), and strip tillage. The best type to use depends much more on the particular climate and soil conditions than on the crop. Crop establishment methods for field crops include flat beds, raised beds and strip tillage. Conventionally the soil is prepared by a primary tillage consisting of one to two deep ploughings with mould board ploughs or chisels to uproot the old stubbles and break the land into clods. This is followed by a secondary tillage with two to three harrowings to break the clods and bring the soil to a fine tilth. If planting is done in a system of ridges and furrows then a fine tilth is not so necessary. But for flat-bed planting a good tilth seems essential. On sloping land ridges and furrows are made along the contours and the cane is planted in the furrow and covered by breaking one ridge. Another unbroken ridge conserves soil and moisture and prevents soil erosion.

4.1.1 Flat beds

Flat beds are used where water availability is adequate and there are no drainage problems and are simple to prepare. In some areas, crops like maize, wheat, rice, sorghum, and beans are started out on a flat bed. However, legumes and maize crops are sensitive to waterlogging caused by heavy rains or flood irrigation, particularly on low permeable fine-textured soils and produce lower yields on flat compared to raised beds (Ram et al., 2005). Therefore, in maize and beans, as the season progresses, soil is thrown into the crop row to mound up the plants; this is called "hilling-up" or earthing up and is done to control in-row weeds, provide support, and improve drainage. Generally, crop establishment on flat surface coupled with flood irrigation are used in different crops and cropping systems that requires more water for irrigation.

In South Asia, rice is commonly grown by transplanting 3 to 4-week-old seedlings, grown in nurseries, into puddled and continuously flooded soil. The advantages of the traditional transplanted puddled rice system of crop establishment include increased nutrient availability (e.g. iron, zinc, phosphorus), weed suppression and easy seedling establishment. The pumping of water for puddling in peak summers in north-west Indo-Gangetic plains (IGP) causes problems of declining water table. Huge water inputs and labour costs for transplanted rice have reduced profit margins which promoted to switch to alternative establishment methods, such as direct sowing and mechanism transplanting. A number of different transplanters are now being used to establish rice crop. Machines range in size from a two-row, walk-behind models to eight-row, ride-on models. Land must be well prepared for machine transplanting. The soil needs to be level and have sufficient bearing strength to carry the machine and support the planted seedlings. Fields may need to be drained one or two days longer than they are for hand transplanting to stop seedlings floating. Most mechanical transplanters place seedlings in rows either 20-30 cm apart with in-row spacing determined by ground speed or head speed of the transplanter. Simultaneously, the availability of high-yielding, short-duration varieties and chemical weed control methods have made to switch to technically viable direct seeding of rice (Kumar and Ladha, 2011). Direct seeding of rice (DSR) can solve the problems associated with transplanting and increase the net return if the yield is more or less comparable with transplanting. Changes in crop establishment have important implications for farm operations, including primary tillage, seedbed preparation, planting, weeding, and water management.

There are three principal methods of establishing the DSR: dry seeding (sowing dry seeds into dry soil), wet seeding (sowing pre-germinated seeds on wet puddled soils) and water seeding (seeds sown into standing water), thus avoiding the nursery bed preparation and transplanting operations. Wet-DSR is currently practiced primarily in southeast Asia. Dry direct-seeded rice (D-DSR) involves drilling or sowing in rows using precision planters. With the elevating shortages of water, the incentive to develop and adopt D-DSR has increased. Direct seeding helps reduce water consumption by 20-30% as it eliminates raising of seedlings in a nursery, puddling, transplanting under puddled soil and maintaining 10-12 cm of flood water in the field (Kumar and Ladha, 2011). D-DSR have less methane emissions (Wassmann et al., 2004) and hence offer an opportunity for farmers to earn from carbon credits than transplanted rice system. High weed infestation is a major constraint for broader adoption of DSR. Likewise, micronutrient deficiencies such as Zn and Fe, due to imbalanced N fertilization and high infiltration rates in DSR, are of major concerns. Yield in DSR is often lower than transplanted rice principally due to poor crop stand, high percentage of panicle sterility, higher weed and root knot nematode infestation (Kumar and Ladha, 2011).

4.1.2. Raised Beds

i. Fresh beds:

Crops can also be grown on raised-up beds or ridges. They are especially advantageous for clayey soils under high rainfall or wherever else drainage is likely to be poor. They can also be used in many other situations. Where crops are furrow irrigated, raised beds or ridges are essential so that the water can flow down the furrows between them. Bed shapers are used to form soil from flat land into raised crop beds, turning the soil as it shapes the bed (see chapter 3.1.2). The size of the bed depends on the crop being farmed. In this technique the field is divided into narrow strips of raised beds separated by furrows. The crops are planted on the bed surface and irrigation water is applied through the furrows. The bed surface remains almost dry and the lateral water movement fulfills the crop water requirement. The infiltration rate of the furrow bottom remains almost zero due to compaction developed by tractor and machinery movement and irrigation water which facilitates the lateral water movement of irrigation water into the bed area. Generally, a single row is planted on the top of each bed for row crops like maize, soybean, cotton, sorghum, sunflower and dry bean, 1-2 rows per bed are planted for crops like chickpea and canola, but 2-4 defined rows, spaced by 15- 30 cm depending on bed width are used for wheat (Aquino, 1998). Height of raised beds: Raised beds are usually 10-30 cm high. The best height depends mainly on soil texture and moisture considerations. For example, raised beds are often 20-30 cm high on clayey soils under high rainfall where poor drainage is likely to be a problem. On coarse-textured soil under the same conditions, bed height might be 15-20 cm. When raised beds are used in drier conditions, a bed height of 10 cm or leas may be best to avoid excessive moisture loss due to evaporation from the exposed sides. Width of raised beds typically varies from 67-130 cm**.** Raised beds usually aren't a good choice during the rainy season, because they dry out more quickly than flat or sunken beds; also, water tends to run off them and be lost into the alley-ways. These disadvantages can be partly overcome by mulching the bed with, and by reducing bed height to 10 cm or less. Advantages of raised beds include: (i) ability to carry out field operations such as weeding, fertilizer application and thinning, and (ii) much better drainage compared with flat beds. They provide a greater layer of topsoil, because they're made by dragging in topsoil from the surrounding alleyways (because of this, they're also likely to be looser than flat beds).

Adaptation of raised beds technology has been proved successful on farms, which suffer frequent water logging over significant proportion of the cropping area. Farmers adopting furrow-bed system for cotton and reporting 20 to 50% saving in water in addition to increase in yield of seed-cotton (Barkhout et al., 1997). Other studies showed that raised beds/ridges and furrow irrigation resulted in an increase of 20-25% in the yield of wheat (Ram et al., 2005). A number of studies from South Asia have shown that crop yields with raised bed planting were either similar or higher to flat bed planting system. However, bed planting of maize had 20 – 30 percent higher water use efficiency (WUE) in comparison with flat planting of farmer practice. Overall comparison of maize – wheat cropping system showed that there were 16 and 22 percent water saving with bed planting in comparison with flat beds. Thus, practice of flat surface planting of maize and of wheat can be replaced with bed planting to save water, labor and improve maize-wheat system productivity and WUE or water productivity (WP).

ii. Ridge-Furrow planting:

In low rainfall regions, water availability is the main limiting factor for crop production. Thus, the development of resource conservation methods to reduce the use of irrigation water to sustain high grain yields and increase the WP is important for crop production in both semi-arid and sub-humid regions. Ridge- furrow (e.g. 30 cm wide each and 15 cm high ridges) can be very successful for rainwater harvesting for obtaining high yields and WP in maize and wheat (Li *et al.*, 2013). In the ridge-furrow system, crop is planted in furrows instead of on raised beds and the limited rainfall is collected within the planting furrows, runoff from heavy rain is reduced. Moreover, surface mulch (plastic film or organic material) can be used on ridges to decrease water evaporation.

iii. Permanent Raised Beds:

Generally, farmers practicing the fresh bed planting technique are currently removing or incorporating the crop residues, destroy the beds by tilling the soil, and make the beds again before the next crop. Permanent raised bed (PRB) planting is a form of controlled traffic, which reduces soil compaction. PRB with residue retention are gaining more attention in recent years with the rising concern over degradation of natural resources, and to offset the production cost (Ladha et al., 2009; Saharawat et al., 2012). The origin and use of PRBs have traditionally been associated with water management issues, either by providing opportunities to reduce the adverse impact of excess water on crop production or to irrigate crops in semi-arid and arid regions for both irrigated and dry land areas (Sayre and Hobbs, 2004; Gathala et al., 2011). The PRB technique of crop establishment can reduce cultivation costs and increase sustainability of maize-wheat systems (Govaerts et al., 2005). Moreover, it allows the use of lower seeding rates than with flat bed planting systems and reduces crop lodging. As experience has been gained with bed planting and appropriate implements have been developed, farmers who grow crops on beds can now simply reshape the beds before planting the next crop and retain all or part of the crop residues on the surface, a practice referred to as PRB planting. In PRB technique the bed-furrow system once developed is not destroyed seasons after seasons. The bed renovator consists of two or three furrowers depending on the size of the raised beds for cleaning the furrows and two horizontal blades that cuts the bed at the base of crop root zone without disturbing the top of the bed. In PRB system production increases of 20-100% are achieved and irrigation application efficiencies are improved. Jat et al. (2013) reported that both PRB and ZT flatbed systems were superior in terms of yield, WP, profitability and soil physical conditions than conventional flat beds in maize-wheat system. Akbar et al. (2007) reported that farmers using PRB system saved about 36% water for wide (130 cm) beds and about 10% for narrow beds (65 cm) and grain yield increase of about 6% for wheat crop and 33% for maize crop was recorded. Permanent raised bed cropping system could be practiced to save water at the field application level and also have the capability to enhance production. Furrow bed system had also helped prevent water logging to a significant extent as excessive water can be drained more efficiently compared to basin/flood irrigation. Sayre, (2003) reported that wheat and maize planted on beds on average saved 29% of water as compared to flat in Asian countries. The benefits of higher profits and better nutrition by planting high value crops such as mung bean, potato, pulses, cotton, tobacco and maize with the raised bed system (Ram et al., 2005). Establishing rice and maize on PRB, using straw as mulch, has produced higher grain yields of rice, wheat and maize using 38% less irrigation water than crops sown on ploughed land. Increased productivity has been attributed to higher levels of soil nitrogen and generally better soil conditions (Gathala et al., 2013).

Advantages of raised bed planting technique in Egypt's Al-Sharkia compared with conventional flat surface irrigation include: (i) 25 percent average saving in applied irrigation water; (ii) 30 percent average increase in grain yield; (iii) 73 percent increase in WUE; and (iv) 30-50 percent saving in the quantity of seed used for planting. Instead of spreading water over the entire surface area – the practice most commonly applied by farmers – raised-bed planting collects water more efficiently, applying this precious resource where it is most needed. In addition, raised-bed planting brought savings in energy and labor. The average time needed to pump water to irrigate one hectare (ha) of wheat planted on a raised bed was 29.4 hours, compared to 43.9 hours on a flat field. The subsequent reduction in the costs of labor and fuel – approximately 33 percent – contributed to a rise in farmer incomes (https://www.icarda.org/media/news/raised-bed-planting-maximizing-water-use-efficiency}.

iv. Raised -Sunken beds:

In northeastern region of India, rainfed rice is the major food crop, occupying about 72% of the total cultivated area. However, quite often rice crop is suffered from soil moisture stress during later growth stage. Farmers are not in position to take any crop during winter (rabi) season because of severe moisture stress. Therefore, proper land configuration is must for utilizing the residual soil moisture effectively for rabi crops cultivation. A simple land configuration through raised and sunken bed (RSB) system, in this context, is a useful technology for proper land and water management, inter-plot water harvesting to increase crop intensity in the paddies of the north eastern region of India.

RSBs are designed to maximise water collection and store water until it can be absorbed by the soil. In shallow water or high rainfall regions (e.g. north-eastern region of India), rice can be grown in the sunken beds (30 cm deep) and different vegetable are grown on the raised beds. RSB of 1 m width each (1:1 ratio) are developed by cutting and filling method. Raised beds height is maintained as per the requirement of the crops, water table and varies from 40 to 60 cm. In areas, where water table is high and standing water remains there at rice harvest, proportion of raised bed area may be reduced to 40 % and height is increased to provide better moisture gradient. The raised beds are leveled in such a way that the 50 % of run-off water from half of the each raised bed will drain off into its intervening sunken beds to promote inter-plot water harvesting. Raised beds can be kept permanent up to 4–5 years and thereafter, new beds scan be prepared after dismantling the old beds for better results. Selections of component crops need to be suitably planned for efficient utilization of water and to increase overall system productivity. significant improvement in cropping intensity, productivity, employment, and income of farmers due to adoption of RSB land configuration compared to farmers' practice of rice monocropping. Under rainfed conditions, quite often rice crop is suffered from soil moisture stress during later growth stage. Farmers are not in position to take any crop during winter season because of severe moisture stress. Therefore, a simple land configuration through RSB system, in this context, is a useful technology for proper land and water management, inter-plot water harvesting to increase crop intensity. Rice can be grown in the sunken beds (30 cm deep) and different vegetable are grown on the raised beds. Das et al. (2015) evaluated RSB land configuration (removing the surface soil layer from an area and depositing on the adjacent area to a height of about 50 cm by cutting and filling method) in rice-based cropping systems. They obtained the highest rice-equivalent yield and net returns in raised and sunken bed system with rice + cabbage (*Brassica oleracea* L.) -malabar spinach (*Basella abla* L.) sequence which was followed by rice + tomato (*Lycopersicon* esculentum)-ridge-gourd [*Luffa acutangula* (L.) Roxb.] sequence. Conventional rice cultivation yielded the least (3.19 t/ha).

4.1.3. Strip-tillage

Strip tillage is a conservation system that uses a minimum tillage by disturbing only the portion of the soil that is to contain the seed row. This type of tillage is performed with special equipment (Fig. 4.1). Each row that has been strip-tilled is usually about 20 to 30 cm wide. Strip-till systems requires a high-horsepower tractor; however, the energy requirement is less than with CT systems (https://www.ag.ndsu.edu › publications crops). Strip-tillage, which creates a soil environment that enhances seed germination, is an alternative to ZT in areas where poorly drained soils are dominant. Where soil moisture conditions are suitable, strip-tillage creates narrow-width tilled strips to increase early spring soil evaporation and soil temperature in the top 5 cm. Fertilizer is often injected into the strip during strip-tilling.

Tilled strips correspond to planter row widths of the next crop. Next crop is planted into the tilled strips.

Figure 4.1. A field planted using strip-till. Notice the crop residue of prior crop between the growing crop rows (https://www.ag.ndsu.edu › publications › crops)

Zero-till planters have a disk opener and/or coulter that is located in front of the planting unit This coulter is designed to cut through crop residue and into the hard crust of the soil. After the coulter has broken through the residue and crust, the disk opener of the planting unit slices the soil and the seed is dropped into the furrow that has been created and then a press wheel (if provided) closes the furrow. With strip-tillage systems at the same time the field is strip-tilled, the fertilizer or chemical may be applied. Strip tillage has some similarities with ZT systems because the surface is covered with residue. Strip till allows an aerobic condition, and it allows for a better seedbed than no-till. Strip-till conserves more soil moisture compared to intensive tillage systems. Both fertilizer application and strip-tillage can be performed in one operation. The basic requirements for strip-tillage to be effective are accuracy in matching tillage equipment on the tool bar with the planter and placement of seeds in the tilled zone. strip-till conserves energy and fuel, and reduces costs because only partial tillage occurs. It reduces soil erosion because crop residue covers most of the soil throughout the year. It releases less carbon into the atmosphere and maintains higher levels of soil organic matter.

References

Akbar, G., Hamilton, G., Hussain, Z. and Yasin, M. (2007). Problems and potentials of permanent raised bed cropping systems in Pakistan. Pakistan J. Water Resour.. 11: 11-21.

Berkhout, N.M. Yasmeen, F. Maqsood, R. and Kalwij, I.M. (1997). Farmers use of basin furrow and bed furrow irrigation systems and the possibilities for traditional farmers to adopt the bed furrow irrigation method. IIMI-Pak, Lahore, Report No. R-33.

Das, A., Layek, J., Ramkrushna, G.I., Patel, D.P., Choudhury, B.U., Chowdhury, S. and Ngachan, S.V. (2015). Raised and sunken bed land configuration for crop diversification and crop and water productivity enhancement in rice paddies of the north eastern region of India. Paddy Water Environ. 13, 571-580.

Govaerts, B., Sayre, K. D., Deckers, J. (2005). Stable high yields with zero tillage and permanent bed planting? Field Crop. Res. 94,33–42.

Jat, M.L., Gathala, M.K., Saharawat, Y.S., Tetarwal, J.P., Gupta, R. and Yadvinder-Singh (2013). Double no-till and permanent raised beds in maize–wheat rotation of north-western Indo-Gangetic plains of India: Effects on crop yields, water productivity, profitability and soil physical properties. Field Crops Res. 149, 291-299.

Ladha, J.K. Yadvinder -Singh, Erenstein, O, Hardy, B. (eds.) (2009). Integrated Crop and Resource Management in the rice-wheat systems of south Asia. International Rice Research Institute, Los Banos, Philippines. 395 p.

Li, C., Wen, X., Wan, X., Liu, Y., Han, J., Liao, Y., Wu, W. (2016). Towards the highly effective use of precipitation by ridge-furrow with plastic film mulching instead of relying on irrigation resources in a dry semi-humid area. Field Crop Res 188, 62-73.

Kumar, V. and Ladha, J. K. (2011). Direct seeding of rice: recent developments and future research needs. Adv. Agron. 111, 297–413.

Ram, H., Yadvinder-Singh, Timsina, J. Humphreys, E., Dhillon, S.S., Kumar, K. and Kler, D. (2005). Performance of upland crops on raised beds in northwestern India. 41-58. In "Evaluation and performance of permanent raised bed systems in Asia, Australia and Mexico". (Eds. C.H. Roth, R.A. Fischer and C.A. Meisner). ACIAR Proceedings No. 121. Australian Centre for International Agriculture Research. Canberra, Australia.

Saharawat, Y.S., Ladha, J.K., Pathak, H. Gathala, M., Chaudhary, N., Jat, M.L. (2012). Simulation of resource-conserving technologies on productivity, income and greenhouse gas emission in rice-wheat system. J. Soil Sci. Environ. Manage. 3, 9-22.

Sayre, K.D. (2004) Raised-bed cultivation. In: Lal R (ed)Encyclopedia of soil science. Marcel Dekker, Inc

Sayre, K. and Hobbs, P. (2004). The raised-bed system of cultivation for irrigated production conditions Sustainable agriculture and the international rice-wheat system. Marcel Dekker, Inc., New York (USA). pp. 337-355.

Suggested reading material

FAO (2009). Talking about Money. No. 3: Explaining the Finances of Machinery Ownership; Jennifer, H., Ed.; Rural Infrastructure and Agro-industries Division, Food and Agriculture Organization of the United Nations: Rome, Italy, 2009; p. 38.

Sims, B.G., Röttger, A. and Mkomwa, S. (2011). Hire Services by Farmers for Farmers; Diversification booklet 19, Rural Infrastructure and Agro-Industries Division, Food and Agriculture Organization of the United Nations: Rome, Italy, p. 8

HYPERLINK "http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-5035/PSS-2134web.pdf" Strip-till Considerations in Oklahoma (PDF) pods.dasnr.okstate.edu. Oklahoma Cooperative Extension Service. pp. 1–2. Retrieved 8 July 2018.

4.2 Nutrient Management in CA

Introduction

Fertilizers are an important input for increasing global agricultural production and account for approximately half of the energy inputs in cereal production worldwide. The future challenge in nutrient management is to manage fertilizers and soil in such a way that food demands are continuously met and soil remains sufficiently healthy to support adequate food production with minimal environmental impact. The fertilizer-use efficiency (FUE) is generally low due to improper fertilizer management practices, and inadequate and imbalance use of fertilizers.

Under the best management practices only 30-50% of this applied N is recovered (RE) by crop plants and more than 50% of the N not assimilated by plants becomes a potential source of environmental pollution – groundwater contamination, eutrophication, acid rain, global warming and stratospheric ozone depletion. While N losses cannot be avoided completely, there is certainly a scope to minimize losses with new and innovative precision N management techniques and technologies. The average recovery efficiency for fertilizer P is 15-20% and 50–60% for K under various cropping systems and soil types.

The key issues for enhancing FUE include maximizing yield and crop uptake per unit of nutrient applied thereby enhancing farmer profit and minimizing environmental concerns. The wide range of approaches are available for increasing FUE include the right form, right rate, right method and right time of application (4R stewardship); matching nutrient supply with crop demand. Site specific nutrient management (SSNM) captures the spatial and temporal variability in soil fertility and provides an approach to "feeding" crops with all the required nutrients based on crop's needs and thus improves the crop yield. Various tools, techniques and decision support systems developed and used for soil-based and plant-based precision nutrient management under conventional agriculture systems will also be applicable to CA systems. Nutrient management is an important aspect of CA for crop productivity and for the adoption of CA by farmers.

Presently, there is a large knowledge gap in understanding of nutrient management in CA systems, particularly in South Asia and Africa. The fertilizer recommendations calibrated mainly based on traditional tillage-based systems, are not necessarily appropriate for CA systems. The 4R nutrient stewardship must be formulated taking into account the specific nutrient dynamics of CA systems. Developing effective nutrient management strategies in CA will need (1) better understanding of the nutrient dynamics; (2) proper assessment of the nutrient contribution from different types and levels of retained crop residues to supplement external nutrient inputs; 3) developing scalable precision nutrient management strategies and supporting tools; and (4) quantifying and conveying the economic and environmental benefits of these new tools and techniques of nutrient management to appropriate stakeholders. Globally, research evidence suggests that adoption of CA based management practices under different production systems and ecologies can address the emerging challenges of low FUE. CA approach recognizes that proper and efficient use of land, fertilizers and water resources is cardinal for sustainable farm productivity.

Nowadays the term nutrient or FUE gained more attention with the rising of fertiliser costs and continued concern over soil and environmental pollution. FUE is an important index that can be used in CA in order to quantify the different nutrient management practices. The FUE can be viewed from different perspectives based on yield (agronomic efficiency, AE), recovery or removal (recovery efficiency, RE). Among the most common expressions of FUE is the RE of fertiliser applied based on nutrients recovered in above ground plant biomass. FUE can also be measured by using the fertilizer labeled with a stable isotope, e.g., ^{15}N for N and radioactive isotope, e.g ^{32}P for P, to differentiate fertilizer nutrient from indigenous soil N or P. Generally apparent fertilizer recovery efficiency, which is more easily measured, is the total nutrient uptake (in aboveground parts of the crop at maturity) at a given fertilizer rate minus the uptake at zero fertilizer rate, divided by the amount of the nutrient applied.

4.2.1 Nutrient Dynamics and Management Strategies in CA

Nutrient management is the science and practice of applying nutrients to crops that link soil, crop and weather factors to achieve optimal FUE, crop yields and economic returns, while reducing nutrient losses and negative impacts on the environment. Both productivity and FUE must increase to supply quantity and quality food at an affordable price. Cost of production must remain low while productivity increases to meet projected food grain demand. CA improves FUE as it reduces soil erosion and prevents nutrient loss from the field. Deep placement of fertilizers with the seed drill will increase FUE compared with broadcasting in the traditional system. Long-term experiments have indicated an increased availability of nutrients under CA owing to microbial activity and nutrient recycling through crop residues and legumes in rotations.

Several nutrient management strategies have been worked out to improve FUE to achieve better synchronization between the supply and requirement of nutrients by a crop. The methods of nutrient management should be innovative, efficient and profitable. Better nutrient management results in reduced inputs and increased efficiency. In pursuance of holistic fertiliser management, it is inevitable to:

i. make soil test and crop need based applications that not only equal crop removals, but also adequately replenish all deficient nutrients,

ii. adopt efficiency enhancing fertiliser methods, times, sources and doses, and

iii. practice integrated nutrient management with supplementary supply of indigenous sources and resources.

Nutrient management can become more complex with crop residue management because of higher residue levels and reduced options with regard to method and timing of nutrient applications. Few researchers claim a greater likelihood of more immobilization, denitrification or leaching of applied N in CA systems requiring higher initial N fertilizer application. ZT and residue in CA system means the timing and method of fertilizer application is very important. Management strategies for increasing FUE involve manipulation of soil, plant, climatic, and fertilizer variables. These strategies involve soil sampling and analysis, crop monitoring and sampling, form of fertilizer and time of application, irrigation, and precision agriculture. The FUE can be increased by adopting appropriate nutrient management strategies (better timing, site-specific management, fertigation, use of nitrification and urease inhibitors) and nutrient efficient cultivars/genotypes through crop breeding. The controlled release fertilizers have a theoretical advantage over other, more knowledge-intensive forms of fined-tuned N management in a sense that the knowledge is 'embedded' in the product to be applied. The efficiency of nutrient use can be increased by adoption of 4R Nutrient Stewardship, an innovative approach for precise fertilizer practice which is considered to be economical and environmental dimension of fertilizer management important for sustainability of agricultural systems. Unlike in conventional cultivation, nutrient management under CA farming is a challenging issue, application of manures and fertilizer nutrient in the amidst of crop residues is always a challenging task. According to Kassam and Friedrich (2009), nutrient management strategies in CA systems would need to be attended based on the following four general aspects:

i. the soil health (physical, chemical and biological properties of the soil) is enhanced, and the soil organic matter are built up and maintained;

ii. there is adequate residue production and recycled and biological nitrogen fixation and nutrient stocks sufficient to support higher levels of biological activity, and for covering the soil;

iii. there is an adequate access to all nutrients by plant roots in the soil, from natural and synthetic sources, to meet crop needs; and

iv. the soil acidity/alkalinity is kept within acceptable range for all key soil chemical and biological processes to function effectively.

Improvement of N-use efficiency (NUE) in crop production systems needs to focus on achieving synchrony between crop N demand and the N supply from all sources throughout the growing season and thereby reducing N losses. Further significant increases in NUE can be achieved through fine-tuning of nutrient management practices developed for CT based agriculture. In a fully established CA system, the aim of fertilizer nutrient management is to balance or maintain soil nutrient levels, replacing the losses resulting from the nutrients exported by the crops. Because CA systems have diverse crop mix including legumes, and nutrients are stored in the soil organic matter, therefore nutrients and their cycles must be managed more at the system level. The nutrient management practiced in CA based on blanket recommendation are generally similar to that for CT system. However, similar nutrient management CA as in CT, may lead to, in many cases, sub-optimal crop yields, low nutrient use efficiency, lower economic profitability and greater environmental footprints. Most farmers' broadcast nitrogenous fertilizers in wheat fields at the time of sowing and subsequently in standing crop. In general, the broadcasting of fertilizer nutrients results in plant roots to become surface feeder, whereas drilling facilitate roots to grow deeper. Deeper root efficiently forages nutrients systems available in the deeper layer which reduce the leaching losses of the nutrients and deeper root system reduced crop lodging. Site-specific nutrient management (SSNM) is a set of nutrient management principles, which aims to supply a crop's nutrient requirements tailored to a specific field or growing environment.

Large number of studies on CA based system across a range of geographies suggest positive effects on soil health parameters (see section 5). An increase in release of nutrients with time is documented in long-term experiments following CA principles due to higher level of nutrient cycling and microbial activity. Therefore, we need to have a paradigm shift in nutrient management strategies under CA when we shift from CT-based management. In CA production systems, tillage machinery innovations are made to allow separate seed and fertiliser band placement. Research on the potential impact of CA on soil nutrient distribution (stratification) and its implications for soil testing and interpretation has not taken place in South Asia. Soil sampling depth also needs modification for CA-Systems as it results in a highly concentrated layer of soil test extractable nutrients (e.g. P and K) in the surface 0 to 7.5 cm with much lower concentrations below 7.5 cm as compared to CT.

Studies from India show higher nutrient availability under ZT compared to CT. In CA, placing urea beneath the soil surface can significantly reduce the volatile losses of NH_3, minimize immobilization in surface residues, increase yields, and enhance NUE. Nutrient management is an important aspect of CA for sustainable crop productivity and its adoption among the farmers.

However, a few studies have been done for standardization of nutrient management protocols in CA which is summarized as below:

The ZT for planting wheat is gaining increasing acceptance with farmers in South Asia because of reduced land preparation costs. In northwestern India and Pakistan, ZT planting has been reported to increase productivity of wheat (Hobbs and Gupta, 2003; Jat et al., 2011). Results from several on-farm trials conducted to evaluate different RCTs in rice and wheat in India, Nepal, and Bangladesh, showed that ZT drill-seeded wheat after burning or removal of loose rice residue, ZT drill-seeded wheat with rice residue mulch and permanent bed-planted wheat performed better than the farmers' practice of conventional till wheat (Ladha et al., 2009). Mulching in ZT wheat is increasingly being favored due to recent developments of appropriate machinery (Sidhu et al., 2015). As reviewed by Bijay-Singh et al. (2008), an examination of 39 data sets from India and Bangladesh with ZT wheat revealed that mulching rice residue often increased yield. As the concept of CA is a recent introduction in South Asia, a very few studies are available on nutrient management in wheat planted under ZT and residue retained conditions.

a. Nitrogen dynamics and management

i. Nitrogen dynamics

CA, through its three key principles (tillage, residue management and crop rotation), is expected to influence the chemical and biochemical processes considerably leading to altered nitrogen (N) dynamics in the soil.

i. High microbial population coupled with high C:N ratio of crop residues may lead to initial immobilization of N and is expected to reduce N availability to plants at initial stages of crop growth in the initial years (1-3 years) or initial growing phase of the crop, but will supply additional N through mineralization in subsequent years, Higher immobilization in CA systems can increase the conservation of soil and fertilizer N in the long run, and the higher initial N fertilizer requirements decrease over time because of reduced losses by erosion and the buildup of a larger pool of readily mineralizable organic N. In the following years after adoption of CA, soil microorganisms increase and the essential nutrients are efficiently recycled leading to lower need for chemical fertilizers.

ii. In high residues on soil surface, efficient N fertilizer management is a challenge because of greater N immobilization and higher losses of N via ammonia volatilization than when residues are burned or removed from the field. When urea is broadcast-applied under CA systems, the potential for immobilization and volatilization are greater compared with CT. Both of these processes can be greatly reduced or minimized by the practices/ activities such as deep placement so that ammonia formed from urea hydrolysis can be adsorbed by soil particles.

iii. The lesser mineralization in ZT soils and common practices of deep placement of N at crop establishment and splitting of N-application to match crop demand can considerably decrease the denitrification potential in ZT systems.

iv. CA increases total N content, which is closely related to total SOC, as the N cycle is closely linked to the C cycle. Significant increases in total N have been measured with increasing additions of crop residues.

v. N is returned to the system via mulch mineralization, regulated by C:N ratio and lignin content of the aboveground and root parts of the crops. The continuous increase in surface and soil biomass and in soil biological processes in CA facilitate the formation and existence of a nutrient balance which leads to crop plants that are healthier.

vi. Crop rotations with legumes as cover- and intercrops contributes to nutrients recycling and biological N fixation reducing the need for chemical fertilizers. The amount of N fixed by legumes depends on the soil–plant environment.

vii. Greater N is fixed from the atmosphere by all kinds of free-living organisms in undisturbed soils under CA, which can make a contribution to maintaining a positive nitrogen balance for the cropping system compared to CT systems.

viii. In CA, ZT and organic mulch will improve soil moisture regime and nutrient dynamics that in turn will influence nutrient response and economic profitability.

ix. CA systems accumulate a layer of crop residues on the soil surface and soil microbe populations tend to increase with surface residue. Slower decomposition of crop residues left on the soil surface can prevent fast leaching of nutrients through the soil profile.

x. The SOM is redistributed mainly in the top 5- cm of soil in continuous CA production systems while it is somewhat uniformly distributed throughout the profile in CT systems. Such distribution of SOM in CA systems influences the dynamics and efficiency of N as the rate of microbial activity increases at the soil-residue interface.

xi. Under CA, the increased rate of infiltration due to continuous pores between the surface and subsurface may lead to more rapid passage of soluble nutrients (NO_3) deeper into the soil profile than tilled soil.

ii. Nitrogen management

The efficient use of N fertilizer is important for crop yield, the environment, and depends on the level of available N in the rooting zone. Proper N management is crucial to avoid N deficiency in CA, as most of top-dressed N may get lost as a result of immobilization, volatilization and leaching when applied on top of residue. The changes in N dynamics in soil with time need to be factored in while designing N management in CA. The conventional N recommendations for conventional farming systems are not necessarily valid as a basis of fertilizer recommendations for CA. Targeting higher crop yields with high N application rates is the key strategy of N management in CA systems. A more efficient utilization of fertilizer with CA production system has been reported in CA compared with CT. During sowing, N can be applied in bands to prevent immobilization and provide young seedlings with adequate N. One-time application of N, involving neem-coated urea and sulphur-coated urea compared to prilled urea under CA, proved more efficient in increasing yields and N use efficiency in maize-based cropping systems. There is immense scope of coated fertilizers in terms of reducing losses in CA-based system. Use of polythene-coated urea, reduced N losses over normal urea fertilizer in ZT maize. Similarly, in ZT under residue retention, the 100% basal application of coated fertilizer like neem and sulphur coated urea was effective for enhancing NUE and net returns compared to conventional split application of prilled urea in maize system.

Kumar et al. (2010) found that planting of wheat under furrow irrigated raised bed system with three and two rows/bed resulted in yield superiority of 12.5% and 8.3%, respectively, over the flat planting owing to better NUE. Compared to broadcast method of N application, placement of N resulted in significant yield increase to the tune of 8.7%. And increasing the number of split doses of fertilizer N could not compensate for basal N application. Application of fertilizer N in three split doses (1/3 before planting + 1/3 after first irrigation + 1/3 at spike initiation) resulted in significantly higher grain yield, irrespective of the method of planting of wheat.

The adoption of ZT and retaining rice straw on the soil surface may alter the N demand of the wheat crop due to changes in soil temperature and soil moisture under rice straw mulch, which in turn affect microbial transformations of N. Residue retention also leads to increase in SOC, which can induce changes in nutrient transformations in the soil as well as improvement in soil chemical, physical and biological properties (Jat et al., 2018; Sharma et al., 2019). Yadvinder-Singh et al. (2010) studied *in situ* decomposition and N release dynamics of incorporated rice residues using the litterbag technique and found that 7.1 t ha^{-1} rice straw containing 40 kg N ha^{-1} at the time of incorporation released only 6–9 kg N ha^{-1} during the life span of the wheat crop (~ 150 days). With such small amounts of N released from incorporated residue, a benefit of significant savings in fertilizer N is unlikely in short term. However, a reduction in fertilizer N loss via volatilization can lead to high NUE under mulch than under non-mulch conditions (Rahman et al., 2005). Increased NUE in wheat under rice residue retained situation is associated with either a reduced rate of fertilizer N or an increase in grain yield, which exceeds any yield gain arising with mulching in the absence of fertilizer (Bijay-Singh et al., 2008).

There are reports in the literature that high (Gangwar et al. 2006), similar (Yadvinder-Singh et al., 2015) or low (Rahman et al., 2005) N rates are required for wheat planted in straw mulch. Banding of N fertilizers did not result in higher yields than when broadcast under rice straw retained as mulch, thereby suggesting that farmers using the Happy Seeder can retain rice straw as mulch and grow wheat without compromising yield. It may be due to decreased volatilization of applied urea on mulched treatments as the surface wind speed and soil temperature would have been reduced; these factors are known to decrease losses via ammonia volatilization. Surface application of urea fertilizer can lead to substantial loss of N by means of ammonia (NH_3) volatilization and gaseous loss to the atmosphere, especially residues are retained on soil surface. N loss can be minimized by: applying N just prior to a rain or before irrigation and deep placement of the urea into the soil. The adjustments in the timing and rate of inorganic fertilizers should be made to synchronize nutrient supply and crop demand under residue retention. In the CA system, basal dose of fertilizer should be drilled just below the seed row by using seed-cum-fertilizer drill. Yadvinder-Singh et al. (2015) further observed that in wheat sown in rice residue with a Happy Seeder in a sandy loam soil, applying 24 kg N ha^{-1} as DAP at planting and remaining 96 kg ha^{-1} in two equal split doses before first and second irrigation events resulted in significantly higher grain yield and N use efficiency as compared to when 120 kg N ha^{-1}was applied in two equal split doses as in CT wheat in straw removed fields (Table 4.1). A further increase in yield and NUE was achieved by applying 50% to 75% of the total recommended N dose at sowing on a loam soil with the urea portion broadcast or drilled between the rows.

Results from a long-term trial conducted under CSSRI-CIMMYT strategic research platform at Karnal (India) showed that CA based treatments in RW and MW systems after 4 years required 30% less fertilizer N and 50% less fertilizer

K compared to CT-RW system with similar management practices (Table 4.2).

b. Phosphorus and potassium dynamics and management

After N, P and K are the nutrients most likely to limit plant N production. CA in most cases improves the availability of P and K in surface soil layer due to reduced mixing of fertilizer with the soil leads to lower P and K-fixation.

In CA systems, P and K also stays at the surface because fertilizers are is not remixed by tillage. The reduced mixing of fertilizer P with the soil in ZT leads to lower P-fixation. Zero tillage and crop residue mulch conserve and increases the availability of P, K and other nutrients near the soil surface (0-10 cm) where crop residues are added and crop roots proliferate.

i. Nutrient stratification is an important concern in the management of P and K in CA systems. When soil conditions are dry, nutrients near the surface may be unavailable for plant uptake.

ii. The available (labile) P in soil is improved under CA which supports in P nutrition to plants.

Table 4.1. Effect of method and time of N application on yield and nitrogen use efficiency of applied N in zero-till wheat sown into rice residue (Source: Yadvinder-Singh et al., 2015)

N applied (kg ha^{-1}) at			Grain yield (t ha^{-1})	Recovery Efficiency of N (%)
Sowing	Before 1st irrigation	Before 2nd irrigation		
25D+35	60	0	4.42	45.0
25D+35B	30	30	4.29	44.1
25D+65B	0	30	4.27	41.9
25D+95B-0	0	0	4.02	39.1
25D	48	48	4.79	56.7

D- drill, B-broadcast at sowing.

Table 4.2. Response of wheat (t ha^{-1}) to N and K in conservation agriculture (CA) plots under two cropping systems (Source: Jat et al., 2018).

Treatment	CT-RW	CA-RW	CA-MW
N (% of 160 kg N ha^{-1})			
100	5.33a	4.99bc	5.30ab
85	5.12a	5.48a	5.42a
70	4.63b	5.32ab	5.16b
55	3.56c	4.62c	4.98 c
0	2.41d	3.83d	3.68d
K (% of 60 kg K_2O ha^{-1})			
100	5.00a	5.01a	5.35a
50	4.52b	5.06a	5.40a
0	4.36c	4.50b	5.05b

CT- conventional till, RW- rice-wheat system, MW-maize-wheat system

Values with-in the same column differ significantly at P = 0.05 when not followed by the same small letter (s) according to Duncan Multiple Range Test for separation of mean.

iii. CA practices increases availability of P and K near the soil surface

iv. About 80-85% of absorbed K remains in the cereal straw and therefore, residue recycling can markedly increase K availability in CA-based systems. The increased K concentration is likely to be more pronounced for rice and wheat than for maize because rice and wheat takes up large amounts of K, and most of this remains in harvest residues.

v. Soil K pools (non-exchangeable K) are either improved or maintained in CA system, whereas a decline in the same was noticed under CT with residue removal.

vi. Mycorrhizas, which are obligate symbioants, can play an important role in nutrient (P) absorption and translocation to the roots of associated plants. They can induce changes in root morphology and therefore allow larger volume of soil to be exploited for nutrients, particularly those which do not move readily through mass flow or are in relatively immobile form particularly P, ammonium N, Cu and Zn. However, micorrhiza diversity and activity is severely curtained by tillage in conventional systems as soil tillage destroys the hyphal networks of micorrhiza fungi thus affecting nutrient mobilization and uptake.

After 20 years of ZT, extractable P was 42% greater at 0–5 cm, but 8–18% lower at 5–30 cm depth compared with CT treatments in a silt loam soil (Ismail *et al*., 1994). This suggests that there may be less need for P starter fertilizer in long-term CA because of high available P levels in the topsoil where the seed is placed. A significant improvement in phosphorus use efficiency was observed under crop residue retention and P fertilization. Placement of P in zero tillage deeper in the soil may be beneficial if the surface soil dries out frequently during the growing season. Banding of P and K either with, or close to the seed increases crop uptake during the early stages. Sub-surface banding of P, ideally about 6–10 cm below the seed, is highly recommended to promote deeper root growth and avoid stranding these nutrients near the soil surface under the CA system. There may be less need for P fertilizer in long-term adoption of CA because of high available P levels in the topsoil where the seed is placed. Placement of P in deeper in the soil may be beneficial if the surface soil dries out frequently during the growing season. After 4 years, CA-based maize-wheat and rice-wheat systems produced wheat grain yield with 50% of recommended K fertilizer was similar to that with 100% K ha^{-1} in conventional systems thereby saving of 30 kg K ha^{-1} of K fertilizers (Table 2).

c. Micronutrient availability

Similar to major-nutrients, micronutrients like zinc (Zn), iron (Fe), copper (Cu) and manganese (Mn) are present in higher levels under CA systems as compared to CT, particularly near the surface layer due to surface placement of crop residues (Gupta et al., 2007; Jat et al., 2018). The increase in availability of micronutrients in soil is ascribed to the increase in SOM content and release of nutrients from crop residues upon decomposition. Understanding the micronutrient status under CA will be helpful in strategizing nutrient recommendation and management in the region.

4.2.2 4R Stewardship in Nutrient Management

The challenges for plant nutrition management are to maintain (and where possible increase) soil fertility status with sustainable crop productivity to meet demands for food, and to enhance the quality of land and water resources. Environmental impacts can be minimized by matching supply of plant nutrients with crop requirements, and judicious soil and water conservation methods. What farmers need to know is how much of which plant nutrients they should supply and at what stage of plant growth to provide the optimum economic increase in yield without damaging the environment.

The 4R nutrient stewardship concept coined by International Plant Nutrition Institute (IPNI) consists of using the right source of fertilizer, at the right rate, at the right time and in the right place, and has shown positive impacts on FUE, profitability and environment. It involves harmonizing the nutrient application with a specific soil, climate, and crop management conditions. The efficiency of nutrient use can be increased by fine-tuning application rates, timing and placement of the right type of fertilizer to match plant growth. Increase in efficiency results in reduced nutrient losses and, if done properly, significant economic savings. An appropriate source will supply the nutrients in a plant available form, so that nutrients are ready for uptake when the plant needs them. A right source should also suit the physical and chemical properties of the soil, so that the nutrients remain in available forms and are not held strongly by the soil matrix or lost from the soil. Typical examples of inappropriate source would include nitrate application to flooded soils, or surface applications of urea on high pH soils.

Selecting the right fertilizer rate is matching nutrient supply with plant nutrient demand. The selection of a meaningful yield target attainable with optimal crop and nutrient management is the first step for determining the right nutrient rate. An assessment of the quantity of nutrients already present in the soil through soil testing or nutrient omission trials, and estimation of the amount and plant availability of nutrients from other sources namely manure, composts, bio-solids, crop residues, atmospheric deposition, and irrigation water helps finalizing the amount of nutrients that needs to be applied through external sources. Economic considerations are major drivers of deciding appropriate fertilizer rates. Applications timed and targeted at specific growth stages are beneficial to crop yield and/or quality and for optimizing nutrient use efficiency. The synergistic and antagonistic effect of different fertilizer nutrients should also be considered while timing the fertilizer application. Right place means positioning needed nutrient supplies strategically so that a plant has access to them. Plant genetics, placement technologies, tillage practices, plant spacing, crop rotation or intercropping, weather variability, and a host of other factors can all affect which placement is appropriate. However, one of the primary objectives of right nutrient placement is to ensure that roots access nutrients immediately after application, thus reducing the possibility of loss.

4.2.3 Precision Nutrient Management Tools and Techniques

There are limitations of the current approach of fixed-rate, fixed-time fertilization being made for large areas which lead to poor NUE and the use of P and K fertilisers and other nutrients is often not balanced, as a result, profitability is not optimized. Soil nutrient-supplying capacity as determined through soil-test analyses often do not effectively account for total soil nutrient supply during crop growth. Thus, blanket fertiliser application recommendations may lead farmers to over-fertilize in some areas and under-fertilize in others, or apply an improper balance of nutrients. The precision nutrient management is the science of using advanced, innovative, cutting edge, site-specific technologies to manage spatial and temporal variability in inherent nutrient supply from soil to enhance productivity, efficiency and profitability of agricultural production systems. It requires understanding of the spatial soil fertility variability in soils. Precision nitrogen management practices can efficiently reduce fertilizer (N) use in comparison to conventional nutrient management practices. Conventionally, the spatial and temporal variability of nutrients in soils is assessed based on a rigorous field sampling followed by soil testing, both of which involve time and energy. Precision nutrient management can be accomplished by different methods, tools and techniques for increasing the nutrient use efficiency. Some noninvasive optical methods have been developed to estimate chlorophyll content (linked to plant N content) of plant leaves based on leaf greenness, absorbance, and/or reflectance of light by the intact leaf. These include chlorophyll meters, leaf color charts (LCC), optical sensors and ground-based remote sensors. Site-specific nutrient management (SSNM) provides an approach to "feeding" crops with all the required nutrients based on crop's needs and thus improves the crop yield and nutrient use efficiency). The plant-based diagnostic methods such as chlorophyll meter, LCC provide a valuable estimation of the N status of the crop. During the first few years of CA, N is mainly found in organic forms (immobilized) and is not available for plants because the mineralization process in the first years is quite slow and there is a need for application of N fertilizer which can speed up the mineralization process. In the years following the adoption of CA, soil microorganisms will significantly increase and essential plant nutrients will be efficiently recycled leading to less need for fertilizers.

i. Chlorophyll meter or SPAD (Soil Plant Analysis Development)meter

Leaf chlorophyll content is linked with leaf N content because the majority of leaf N are contained in chlorophyll molecules. Therefore, measurement of leaf greenness by chlorophyll meter (SPAD meter) can signal potential N deficiency from an intact leaf tissue early enough to correct it without reducing yields. The effectiveness of chlorophyll meters in improving NUE has been established in rice maize and wheat. Two approaches have been used to guide fertilizer N applications to rice: (a) when SPAD value is less than a set critical reading and (b) when a sufficiency index (defined as SPAD value of the plot in question divided by that of a well-fertilized reference plot or strip) falls below a threshold value (e.g. 0.90 in rice). Despite greater reliability of the sufficiency index or dynamic threshold value approach, the fixed threshold value approach is more practical as it does not require a well-fertilized or N-rich plot. It has also been suggested that different threshold SPAD values may have to be used for different varietal groups. For rice cultivars grown in the Indo-Gangetic plain in India, the threshold SPAD value of 37 or 37.5 has been found to be appropriate for optimum rice yields, whereas for rice cultivars grown in South India, the threshold SPAD value was found to be 35.

ii. Leaf color chart-LCC

Leaf color chart, alternative to SPAD is used to measure the relative greenness of the crop leaf. It is a cost-effective tool for real-time or crop-need-based N management in rice, maize and wheat. It is used to rapidly monitor leaf N status at tillering to panicle initiation state and thereby guide the application of fertilizer N accordingly. The LCC is used at critical growth stages to decide whether the recommended standard N rate will be needed to adjust up or down based on leaf color. There are two major approaches in the use of the LCC. In the *real-time* approach, a prescribed amount of fertilizer N is applied whenever the color of leaves falls below a critical LCC value.

How to use LCC: Take the first LCC reading at 14 days after transplanting of rice. For direct -seeded rice, start taking readings at 21 days after seeding. Randomly select the topmost, fully expanded, and healthy leaf of the 10 plants one from each hill with in the field . Take LCC readings by placing the middle part of the leaf on top of the LCC's color strips for comparison. Do not detach the leaf. Measure the leaf color under the shade of your body, as direct sunlight affects leaf colour readings). The same person should take the LCC readings at same time of the day between 8:00 a.m. and 10:00 a.m. If more than 5 out of 10 leaves have readings below a set critical value (say 4) in transplanted rice, apply urea. Repeat LCC readings every seven days until the first flowering. Preferably use different sets of 10 leaves for subsequent readings. In maize, colour of the first top maize leaf with fully exposed collar is measured using LCC shade 5 at six-leaf (V6) stage and LCC shade 5.5 at silking stage (R1) to guide crop demand driven N applications resulted in improved agronomic and N recovery efficiency in different maize genotypes.

In this approach leaf color is regularly monitored and fertilizer N is applied when leaves become more yellowish-green than the critical threshold value indicated on the LCC. The *fixed splitting pattern* approach provides a recommendation for the total N fertilizer requirement (kg ha^{-1}) and a plan for splitting and timing of applications in accordance with crop growth stage, cropping season, variety used, and crop establishment method. In both the cases, amount of N applied will be less if the crop leaf color is greener and vice-versa. Following LCC-based N management, the rice, wheat and maize yields were either similar higher to that with farmer's practice but with less N fertilizer application. Although most of the above research is related to conventional agriculture but same principles will apply to CA.

iii. Optical Sensor GreenSeeker

GreenSeeker (GS) is a variable rate application and mapping equipment designed for use throughout a growing season. Optical sensors measure visible and near-infrared (NIR) spectral response from plant canopies to generate a vegetative index called NDVI (Normalized Difference Vegetation Index), which measures the nutrient status of the plants based on their size and colour. Here, crop vigor measured as NDVI the basis for N prescription rates. By dividing NDVI (estimate of total biomass) by the number of days from planting to sensing (or emergence to sensing), gives an estimate of biomass produced per day (to count a day, growing degree day must be >0). This index (NDVI/days from planting to sensing or emergence to sensing) is called INSEY (In Season Estimated Yield), a predictor of yield (grain or forage depending on the system) with no added inputs YP0. A critical component of the algorithm is to precisely predict whether or not there will be an in-season response to applied fertilizer N and the magnitude of that response. The Response Index (RI) to added fertilizer N expected is calculated by dividing the average NDVI in the Nitrogen Rich Strip (NRS) by the average NDVI in the test plot. The Response Index (RI) changes in the same field from one year to the next simply because of the marked influence of "environment" on N availability. The environmental conditions conducive to the mineralization of soil organic matter are quite variable and as such the demands for fertilizer N should be expected to be variable from one year to the next as well. In others words the ability of the environment to supply N (via mineralization of soil organic matter and/or deposited in rainfall) is quite variable and we need to take this amount of N supplied by the environment into consideration when making mid-season fertilizer N recommendations.

The calibration of optical sensor relates the grain yield of the crop to the NDVI readings. Once calibration is complete, optical sensors require: (1) establishment of a reference N-rich strip in the farmer's field (2) collection of an NDVI reading in the reference strip and in the field where the farmer needs to know how much N should to be applied, and (3) the NDVI readings collected from these two areas in the field together with the date of planting and date of sensing are entered in a mathematical model developed for each region. Rather than using a critical NDVI value for recommending fertiliser N, the optical sensor works out the fertiliser N requirement of the crop on the basis of the difference in N uptake between estimates of yield potential with no added fertiliser N and with fertiliser N application, and an efficiency factor.

Using GreenSeeker optical sensor, robust relationships between in-season GreenSeeker optical sensor-based estimates of yield at Feekes 5-6 and 7-8 growth stages and actual wheat yields have been recorded. Prescriptive N management in the form of applying different amounts of fertilizer N at planting and the crown root initiation stage of wheat, and whether optical sensor-guided N dose was applied at either Feekes 5-6 or Feekes 7-8 stage that generally coincide with 2nd and 3rd irrigation events, influenced the amount of fertilizer N to be applied following the N fertilizer optimization algorithm.

GreenSeeker (GS) is a variable rate application and mapping equipment designed for use throughout a growing season. Here, crop vigor, measured as normalized difference vegetative index (NDVI), is used as the basis for N prescription rates. The results of GS sensor-based N management resulted into similar (in rice) to higher yield (in wheat) with reduced N rates thereby increasing NUE (Bijay-Singh *et al*., 2020).

The study showed that the optical sensor-guided fertilizer N applications resulted in high yield levels and high N use efficiency. Significant improvement in grain yields, agronomic efficiency and recovery efficiency of N have been observed through the GreenSeeker optical sensor-based N application in rice, wheat and maize. A small handheld version that costs a fraction of the original technology (approximately USD 500) is now commercially available.

iv. Site-specific Nutrient Management

Site-specific nutrient management (SSNM) is a set of nutrient management principles that aims to supply a crop's nutrient requirements tailored to a specific field or growing environment. It is an approach of supplying plants with nutrients to optimally match their inherent spatial and temporal needs for supplemental nutrients. The SSNM uses a nutrient balance approach in that, within season nutrient estimation is used to determine the amount of N to be applied at the time of crop establishment, and subsequent application can dynamically be varied to match the spatial and temporal needs of crop through periodic monitoring. It accounts for indigenous nutrient sources, including crop residues and manures; and ensure optimal rates of fertilizer application at critical growth stages to meet the deficit between the nutrient needs of crop and the indigenous nutrient supply.

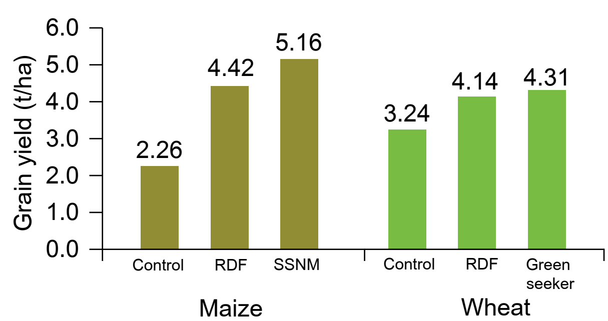
The five basic steps/principles for SSNM include:

1. pre-season calculation of balanced fertiliser rates, based on the difference between the plant's nutrient requirements and the soil's nutrient supplying capacity. This deficit depends largely on the expected yield increase (difference between target yield and yield in nutrient omission plot). An attainable yield target (generally 75-80% of the yield potential) is set;
2. Use of omission plots for estimating indigenous soil nutrient supplies as it integrates the supply from all indigenous sources including organic manures estimated under field conditions;
3. Need-based N management using LCC, SPAD meter and optical sensors for location-specific N management
4. Sustainable crop- and soil-based P and K management. Nutrient requirements for targeted yield goals should take into account the soil nutrient supply estimated from nutrient omission plot, nutrient inputs from irrigation water, biological N fixation and nutrient removal through grain and straw. The estimate of the nutrient rate is based on response and agronomic use efficiency of nutrients. Straw management has a pronounced effect on the maintenance of soil K supply, because about 80% of the K taken up by the cereal crops remains in the straw. Where only small amounts of straw are incorporated after harvest, substantial amounts of fertiliser K would have to be added to balance K removal in straw and grain, and, increasing profitability.

The SSNM approach does not necessarily aim to either reduce or increase fertilizer use. Instead, it aims to recommend nutrients at optimal rates and times to achieve high profit for farmers, with high efficiency of nutrient use by crops across spatial and temporal scale, thereby preventing loss of excess nutrients to the environment. Results from a number of studies showed that SSNM reduced N fertiliser use and increased grain yield compared with farmers' N fertilization practices in rice, maize and wheat thereby increasing N use efficiency.

Results from several studies conducted in Asian countries showed that SSNM led to significant increases in yield, NUE and profitability in rice, wheat and maize. Thus, SSNM could be used in larger domains for improving cereal productivity, nutrient use efficiency and farm profits in CA systems. Few studies on ZT system clearly showed that crop production and SSNM can significantly improve the partial factor productivity of applied nutrients. So, under this scenario modern SSNM tools can provide real time fertilizer recommendation considering 4R nutrient stewardship.

Figure 4.2. Effect of nutrient-management practices on grain yield of maize and wheat under CA



v. Decision Support Systems: Nutrient Expert

Computer or mobile phone-based tools are increasingly used to facilitate improved nutrient management practices, especially in geographies where blanket fertiliser recommendations prevail. Nutrient Expert (NE), a Decision Support System was developed by International Plant Nutrition Institute in collaboration with International Maize and Wheat Improvement Center (CIMMYT) and Indian National Agricultural Research System, for small holder production system of South Asia(http://software.ipni.net; http://blog.cimmyt.org/tag/nutrient-expert). It is easy-to-use, interactive computer-based decision tool that can rapidly provide nutrient recommendation for individual farmers' field in absence of soil testing data.

What can the Nutrient Expert® do?

i. It provides fertilizer application guidelines tailored to each farmer's field
   - right source (e.g. DAP or mixed fertilizer, urea, MOP)
   - right rate – how much fertilizer
   - right time – when to apply

ii. It takes into account:
   - variety type (hybrid, inbred, traditional)
   - site characteristics (soil, climate, water availability)
   - farmer's crop management practices (cropping system, residue management, fertilizer inputs)

iii. Provides options for risk management such as in-season drought (particularly for maize)

iv. Provides an economic analysis of the recommended practice

v. Options for modifying recommendations based on farmer's budget

It synthesizes the on-farm research data into a simple delivery system that enables farmers to rapidly implement SSNM for their individual fields. The set of information includes (Fig. 4.3):

Agronomic data base: Attainable yield, soil fertility indicators or estimates of yield response to N, P and K, fertilizer use efficiency (AE and RE), nutrient uptake, farmers' current yield, characteristics of the growing environment, crop sequence and crop residue management and organic manure inputs.

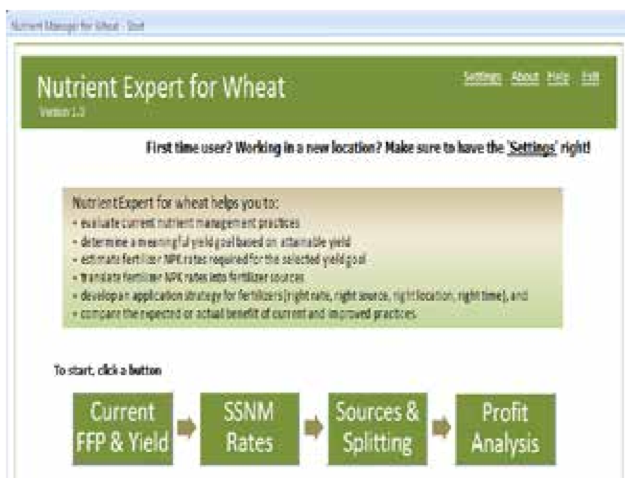
vi. Model development: Data analyses, consultation meetings, algorithm development and programming. The algorithm for calculating fertiliser requirements was developed from on-farm research data and validated over 5 years of testing.

vii. Field validation: Field evaluation of nutrient expert based fertilizer recommendation, farmer's current practice and other fertilizer practices, and model adjustments as needed. The software determines the nutrient balance in the cropping system based on yield and fertilizer/ manure applied and residue retained in the previous crop and combines such information with expected N, P and K response in the concerned field to generate a location specific nutrient recommendation for crops; and

viii. Final step is fertilizer recommendation for a given crop. Fertilizer application guidelines tailored to each farmer's field (right source, right rate, and right time – when to apply).

ix. The software also does a simple profit analysis comparing costs and benefits between farmers' current practice and recommended alternative practices.

Figure 4.3. Nutrient Expert for wheat



Fertilizer management using NE-based nutrient recommendations showed significantly higher grain yield and NUE of maize and wheat in CA in comparison to farmer practice (FP) and state fertilizer recommendation. Better efficiency of nutrients applied according to nutrient expert (NE) recommendations than in farmers' practice indicates that location specific nutrient application rate and better timing of nutrient application (i.e. a greater number of splits and matching physiological demand of the crops) reduced N losses and enhanced nutrient use efficiency. Results from field experiments conducted at BISA farm of Pusa, Bihar showed that drilling of fertilizer nutrients, improved nutrient use efficiency, productivity and profitability of wheat under CA (Table 4.3). Nutrient management using NE improved grain yield and net returns by about 30% over FP.

vi. Nutrient manager

The International Rice Research Institute (IRRI) in collaboration with national partners across Asia incorporated SSNM-based algorithms into a web-based decision support tool, named Nutrient Manager for Rice (NMR), which calculates rates and times of fertilizer (N, P and K) application for individual rice fields in Asia (http://cropmanager.irri.org/home). The tool allows farmers to adjust nutrient application to crop needs based on soil characteristics, water management (irrigated or rainfed), amount of above-ground residue from the previous crop retained in the field and crop variety. The field-specific fertilizer recommendations (rates and time of application) to achieve a target yield set calculated by RCM are unique for each field. Recommendations are based on user-input information can be collected by extension workers, crop advisors, and service providers. It is a computer-and mobile phone-based application that provides small-scale rice, wheat, and maize farmers with site- and season-specific fertiliser recommendations. The software is freely downloadable at http://cropmanager.irri.org/home.

4.2.4 Fertigation Using Drip-irrigation System

Fertigation, the delivery of nutrients through irrigation, is one such strategy that can be integrated into fertilizer regimes, tuned to appropriate application rates and meet crop demand and thereby improve NUE. The rapid adoption of micro-irrigation in agriculture has been largely due to the efficiencies from more precise delivery of water and the multiple benefits of fertigation (simultaneous delivery of water and nutrients) are also widely recognized. In CA, sub surface drip irrigation (SSDI) system can be adopted for increasing water and nutrient use efficiencies. The SSDI system reduces evaporation from the soil surface and allows delivery of water and nutrients directly to the root zone. Simultaneous delivery of water and nutrients directly to roots has been shown to be advantageous for a variety of crops, while minimizing nitrate-leaching losses. Field studies conducted at BISA, Ladhowal, Punjab showed that SDI as well as fertigation in CA-based maize-wheat and RW systems saved 50-60% irrigation water and increased N use efficiency by 25% in rice, maize and wheat compared to CT with flood irrigation system (Table 4.4). Sandhu et al. (2019) reported that fertigation at 10-day interval with five splits in wheat and seven splits in maize under surface drip irrigation system increased the mean N recovery efficiency by 16.5% and 29% compared to furrow irrigation in CA-based wheat and maize, respectively.

Table 4.3. Precision nutrient management in wheat under conservation agriculture (Jat RK BISA, Pusa, Bihar, unpublished).

Tillage Practice	Nutrient Management	Grain yield (t/ha)	Additional cost (INR/ha)	Additional income (INR/ha)
CT	FP	4.26	0	0
PB	Ad-hoc state recommendation	5.31	1000	12350
PB	Ad-hoc SR -80% N in 2 splits, 3rd N split based on GreenSeeker	5.44	1504	13588
PB	Nutrient Expert based NPK rates	5.52	1658	16018
PB	Nutrient Expert based NPK rates-80% N in 2 splits, 3rd N split based on GreenSeeker	5.56	1658	16523

Conclusions and Future Outlook

CA practices influence several soil health parameters (see Chapter 5), increases biological nitrogen fixation by legumes in rotation, exploitation of the deeper soil layers through crops with deep and dense root systems, which have a significant bearing on nutrient management. CA increases availability of nutrients near the soil surface (known as nutrient stratification) where crop residues are retained as mulch. Unlike in conventional cultivation, application of manures and fertilizer nutrient in the presence of crop residues as mulch is always a challenging task in CA farming. It has been acknowledged that better N management is required particularly in the first years of conversion from tillage-based agriculture to CA due to reduction in available N in untilled soil (Theirfelder and Wall, 2011). Evidence shows that in CA systems, nutrient requirements are lower and nutrient efficiencies are higher. However, systematic research nutrient management requirements in CA systems is limited. Various tools, techniques and decision support systems are available to develop SSNM plan for each field and dynamically fine-tune in-season nutrient management to increase the nutrient-use efficiency. The low-cost variants of the optical sensors have been developed and can be used effectively in smallholder systems to make split-N application decisions across variable soil, crop and climate conditions. The improvement in sensor technology and algorithm development needs further research to develop more reliable and suitable models. A wide range of fertilizer products (controlled-release fertilisers, urease and nitrification inhibitors) available in the market which can reduce losses of N and increase NUE need to be evaluated under CA. Studies show that no one method that can be used individually, but a combined approach might help in improving NUE. There is a strong need new scientific thinking and research in the area of nutrient management, to fill the knowledge gap that currently exists about CA in different environments and countries. More research is needed to find the effect of different CA practices on crop yield and nutrient dynamics especially in long-term experiments. Increases in NUE under CA should be studied, especially the use of more nutrient efficient genotypes. Breeding programs for developing highly efficient genotypes should be undertaken under CA conditions in different environments. More research is needed on different aspects of nutrient management in CA systems, as more countries begin to adopt and integrate CA concepts and practices into commercial production activities at both small and large scales for future sustainable production. Precise placement of N-fertilizer through side banding in CA system reduces immobilization (as it separates fertilizer and residue) and volatilization loss. Improved mechanization is needed for fertilizer application at sub surface depth and residue retained condition both for basal application and at later crop growth stages for split application in different crops including tall crop like maize. It is important

Table 4.4. Grain yield, amount of irrigation water, water productivity and partial factor productivity of N (PFP_N) in CA based maize-wheat system on permanent beds at BISA Ladhowal (Punjab)

Treatment	Grain yield (t ha^{-1})	Irrigation water applied (cm)	Water productivity (kg/ha-mm)	PFP_N (kg/kg N)
Maize				
90 kg N ha-1-SSD-ZT	7.62b	8.7	87.6c	34.9a
120 kg N ha-1-SSD-ZT	8.56a	8.7	98.4b	32.5a
120 kg N ha-1- Flood-CT	7.47b	22.0	33.9a	25.2b
Wheat				
90 kg N ha-1-SSD-ZT	5.35ab	18.4	29.1a	59.4a
120 kg N ha-1-SSD-ZT	5.61a	17.9	31.3a	46.8b
120 kg N ha-1- Flood-CT	5.24b	36.5	13.9b	43.7b

SSD- sub surface drip (fertigation), ZT-Zero till, CT-conventional till that medium to long-term studies on CA and nutrient management are conducted in different environments to better guide farmers to successful adoption. More research is needed to find the effect of different CA practices on crop yield and nutrient dynamics especially in long-term experiments. Breeding and selection for nutrient-efficient species or genotypes is important to reduce fertilizer input costs and environmental pollution. Studies have shown significant differences among cultivar performance when evaluated under different agronomic systems. The genotypes developed under conventional agricultural practices may not be suited to CA, which has drastically different soil environment. Increases in FUE under CA should be studied, especially the use of more efficient genotypes. Significant genotype x environment x management interactions have now been well documented in CA. Despite the published studies on breeding for nutrient efficiency, the release of new crop cultivars with improved nutrient efficiency is limited, particularly under CA. Biotechnology offers the opportunity to improve nutrient efficiency in crop plants by transferring the identified genes into other species or using them as molecular markers in breeding programs for CA.

There is a need to develop fertilizer prescriptions and application strategies in line with the 4R and SSNM principles to increase nutrient use efficiency taking changes in nutrient dynamics into consideration under CA based management practices. CA has a challenge pertaining to fertilizer application when residues are present on the soil surface as a significant amount of fertilizers is remained on residue and never come in soil contact if applied through broadcast. Hence the type of fertilizer material (source), rate, time and method of application have to be evaluated in CA properly to increase the crop productivity, input-use efficiencies, farm profits and restore the nutrient supplying capacity and soil health. While more work needs to be done to formulate nutrient management strategies in CA systems, all such strategies would need to ensure that soil health improvement becomes the means of meeting crop nutrient needs in an optimum and cost-effective way within the prevailing ecological and socio-economic conditions.

4.3 Water Management

An adequate supply of irrigation is vital both for ensuring high yields and for reducing drought-related risk in agricultural production systems. When rainfall is not sufficient, the crop must receive additional water from irrigation. However, water is becoming increasingly scarce worldwide and more than one-third of the world population would face absolute water scarcity by the year 2025 (Rosegrant et al., 2002). At present, 2.8 billion people live in water scarce areas, but by 2030, it is expected that about half of the world's population will live in water stressed areas. The worst affected areas would be the semi-arid regions of Asia and Africa. With this faster population growth in these regions, while requirement of food and other agricultural commodities is increasing, future water availability has been declining at a faster rate. In the face of climate change, more irrigation water will be required to counter the predicted increase in evapotranspiration rates and decreases in rainfall in the future. Studies show that there would be at least 10% increase in irrigation water demand in arid and semi-arid regions of Asia with a 1°C rise in temperature. Recurrent droughts have often resulted in severe crop damage, decreased livestock production and widespread food shortages and the most severe impacts of droughts are felt in countries with agro-based economies. Since the imbalance between water demand and water availability has reached critical levels in many regions of the world and increased demand for water and food production is likely in the future, a sustainable approach to water resource management in agriculture is essential.

Various methods can be used to supply irrigation water to the plants. Each method has its advantages and disadvantages that depend on several factors: initial cost, size and shape of fields, soil characteristics, nature and availability of the water supply, climate, cropping patterns, and influences external to the surface irrigation system. These should be taken into account when choosing the method which is best suited to the local circumstances. Despite the low field-level application efficiency of between 40% and 60%, surface irrigation is the most common method of irrigation in most parts of the world. In an environment of limiting resources, farmers can increase the efficiencies of irrigation systems by reducing conveyance losses (e.g., maintenance and rehabilitation of canals), reducing evaporation losses, introducing site-specific applications, appropriate irrigation scheduling and management decisions (e.g., supplementary, full or deficit irrigation). In rainfed areas. strategies such as rain-water harvesting will be beneficial in augmenting already burdened water sources. The practices that can be adopted to assure responsible irrigation usage include: (i). Changing irrigation methods and discouragement of flood irrigation methods, (ii). Appropriate selection of crops to be grown, and (iii). Efficient methods of crop cultivation.

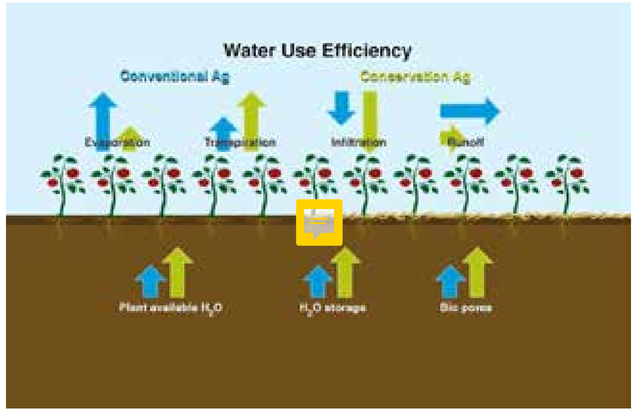
Integration of CA based technologies further improves water use efficiency (better denoted as WP). In CA, farmers need to be encouraged to use pressurized irrigation methods (e.g., drip or subsurface irrigation) that have higher field-level application efficiencies of 70% to 90% as surface runoff and deep percolation losses are minimized. CA practices generally increase the water infiltration and reduce surface runoff, and reduce evaporation loss compared to CT systems. Thus, CA increases soil moisture storage and enhances duration of water availability to crops and crop water productivity. The increases in the soil organic matter levels in CA allow a better water retention in the soil in the entire root zone.

There are several approaches for improving the WP including replacing high water consuming crops (e.g. rice) with lower-consuming ones (maize/soybean) and adopting management and systems improvements to increase productivity per unit of water consumed. The technological options for improving WP varies with crop grown and cropping system followed land texture, topography, available soil moisture regimes and resource endowed with farmers. Among all the agricultural crops, rice is the greatest guzzler of irrigation water among all crops consuming about 80% of the total irrigated fresh water resources in Asia. Alternate wetting and drying, precise land levelling, bed planting and drip irrigation substantially save irrigation water without any reduction in grain yield and improves WP in different crops. Irrigation scheduling in rice is crucial to save the irrigation water as it is the major user of water. To conventional transplanted rice, irrigation at 2-3 days after disappearance of ponded water or irrigation at hairline cracking stage in soil proved better for saving irrigation water at most of the locations in India. In North-West India, CA practices (ZT and residue mulch) takes immediate advantage of residual soil moisture from the previous rice crop (eliminating need for pre-sowing irrigation), as well as cutting down on subsequent irrigation, thereby reducing water use by about 10 cm-hectares, or approximately 1 million litres/ha in rice-wheat system. It would help to save 80 kWh of electricity and reduce emission of 160 kg of CO_2. The important means for improving WP are discussed here as under.

Most common surface irrigation method has field level application efficiency is often 40-50%. Pressurized irrigation or microirrigation systems (sprinkler, surface, and subsurface drip) have the potential to increase irrigation WP by providing water to match crop requirements, reducing runoff and deep drainage losses, reducing soil evaporation and increasing the capacity to capture rainfall. Reports show drip irrigation gave similar or higher yields and 40-50% higher WP compared to surface irrigation. Nearly 20-25% of irrigation water is lost due to unevenness of the fields leading to non-uniformity in germination, poor crop stand, increased weed intensity and uneven maturity affecting yield and grain quality. Precision land levelling by using laser guided land leveller is required for optimum water and nutrient use efficiency, better crop establishment, saving in time for applying irrigation and ultimately more productivity. Improved crop varieties and pest control will affect crop productivity and water use in CA.

Figure 4.4 shows relative quantitative differences in the processes between CT and CA systems. The size of the arrows represents the relative magnitude for the two different agricultural systems. Conventional tillage systems that are designed primarily around annual crops can experience greater water loss through increased runoff, leaching losses and soil evaporation. By contrast, CA systems incorporating zero tillage, diverse rotations and surface mulch can increase crop water use efficiency by simultaneously reducing evaporation and runoff and contributing to soil function improvements that create more and deeper water storage.

Figure 4.4. Possible mechanisms for improved soil–plant–water relations in CA systems (blue arrows) versus conventional agriculture (yellow arrows). The relative magnitude of the process or function is indicated by the length of the arrows. (Mitchell et al. 2019) http://www.cabi.org/cabreviews



Irrigation Scheduling – Frequency and Amounts

Optimization of irrigation amounts in time and space requires scientific irrigation scheduling practices. Scientific irrigation scheduling is a systematic procedure that calculates an estimated future water requirement over relatively short periods of time to meet all crop needs and avoid water overapplication or underapplication. Irrigation scheduling is based on several factors viz. evapotranspiration (ET), plant water status, canopy temperature, soil moisture potential or volumetric water content of soil, dielectric moisture constant. Soil water status and ET-based irrigation methods are more sustainable practices compared with pre-set scheduled irrigation because of the lower water volumes applied. The optimal irrigation is the process of irrigating water exactly equal to crop ET. The real time values of soil moisture, air humidity, shown to be valuable in optimizing crop yields and WP with respect to manual irrigation based on direct soil water measurements.

Soil moisture-based irrigation scheduling involves determination of soil water status (volumetric soil water content or matric potential) within the root zone, and knowledge of the critical threshold for irrigation. When based on volumetric soil water content, the threshold for irrigation is generally expressed as percentage depletion from full of the total plant available soil water holding capacity (the amount of water held in the soil water between field capacity and permanent wilting point) of the root zone. In the second approach, irrigation is scheduled according to soil matric potential (SMP), usually at particular soil depth. SMP is directly related the energy required by the crop to extract water from the profile. The most common methods of determining SMP are tensiometers, and granular matrix sensors which may be read manually or logged. Modern tube tensiometers are relatively cheap, robust and easy to use, consisting of a porous ceramic cup connected to a plastic tube which is connected to a vacuum gauge. Tensiometer measures *in situ* in real time, and are accurate to SMP in the moisture range from 0 to about -80 kPa, and thus cover the range needed for most crops. The uncertain climatic conditions (temperature and relative humidity) may not allow the fixed day intermittent irrigation to be followed especially for rice. Threshold value of SMP for scheduling irrigation depends on type of crop to be grown. For transplanted rice, irrigation is recommended when SMP at 20 cm depth reached −15 kPa. The critical SMP for scheduling irrigation to wheat is -35 to -40 kPa at 20-30 cm depth and for maize is -45 kPa at 20 cm soil depth.

Soil moisture and weather monitoring (climate-based approaches) are used to determine when to irrigate, and soil capacity and crop type are used to determine how much water should be applied. Weather monitoring such as temperature, rainfall, humidity and crop evapotranspiration (ET) data is also used to determine efficient irrigation scheduling. Improving irrigation practices such as by converting from gravity surface irrigation systems to pressurized drip or sprinkler systems can facilitate irrigation scheduling, especially when the system is automated and controlled on the basis of in situ soil water sensors.

Water budgeting is often compared to managing a savings account. The starting point is field capacity, and as water is removed and the soil, it is replaced as needed by the crop. Water budgeting is a quantitative approach using existing models that analyze temperature and crop water use to determine evapotranspiration (ET) rates. When seasonal ET exceeds precipitation, irrigation is required to sustain planted crops. Once the ET rate of your site is determined, this estimated volume of water may be replaced through the use of calibrated irrigation systems that deliver water at a known rate and volume. An additional 10% should be calculated in to compensate for delivery system inefficiencies.

The frequency of irrigation should correspond to the time period required for the soil in the root zone of the crop to dry to approximately 50% of field capacity. The estimated amount of water lost through ET is replaced as needed to maintain the health of the crop. Carefully managed deficit irrigation on agronomic crops would provide the greatest potential for substantially reducing agricultural water use because of the larger land areas that are involved. Advanced irrigation technologies and state-of-the-art delivery systems, will be needed to be able to fully implement successful deficit irrigation strategies.

Irrigation scheduling using soil moisture sensors: As the cost of simple soil moisture sensors drops, these instruments can be used by small and medium size farmers in their systems to monitor

Table 4.5. Various soil moisture monitoring methods used under field conditions

Plant observation	Visible changes in plant characteristics, such as curling and ultimately wilting. Plant moisture status can also be measured using sap flow sensors, infrared guns, and pressure bombs (which measures leaf water potential.
Weather based data	Two weather-based scheduling systems are used to measure the amount of water lost from the crop. These are: (1) evaporation from an open pan water surface, and (2) historical climate data, such as relative humidity, temperature, wind speed and sunshine hours. The irrigation schedules based on 0.9 to 1.2 IW/CPE has been found to be optimum for different crops. Among field crops, rice is the major user of water.
Soil moisture monitoring	Soil moisture is measured by gravimetric method (volume basis) and as a suction of water. Soil moisture suction (or potential) can be used as a measure of plant stress. It is a most practical and simple tool for farmers to use for scheduling irrigation.

soil moisture levels. Such devices provide site-specific data points and are quite accurate and can be used in combination with other techniques to inform irrigation decisions. Soil tensiometers and Electrical Resistance Sensing Devices (ERSDs) are the instruments most commonly used to measure soil moisture. Both must be carefully installed directly in the wetted area of the crop's root zone at 2-3 sites throughout the field for accurate monitoring. Soil moisture sensors are often used in pairs at different depths, e.g., at 15 and 30 cm deep, to provide the irrigator with information on below-ground moisture dynamics. Tensiometers and ERSDs provide soil/water tension readings that can be used to establish irrigation schedules adequate to maintain soil moisture at levels conducive to good crop growth and productivity for different crops and growth stages. Small-seeded crops and dry seeded rice (DSR) require that soils be kept moist in order to germinate effectively. In deciding when and how much to irrigate, the farmers must take into account a variety of factors in addition to soil moisture, including crop needs, and timing of harvest as well as weed management operations to determine an optimum application time and rate.

Methods of Irrigation Application

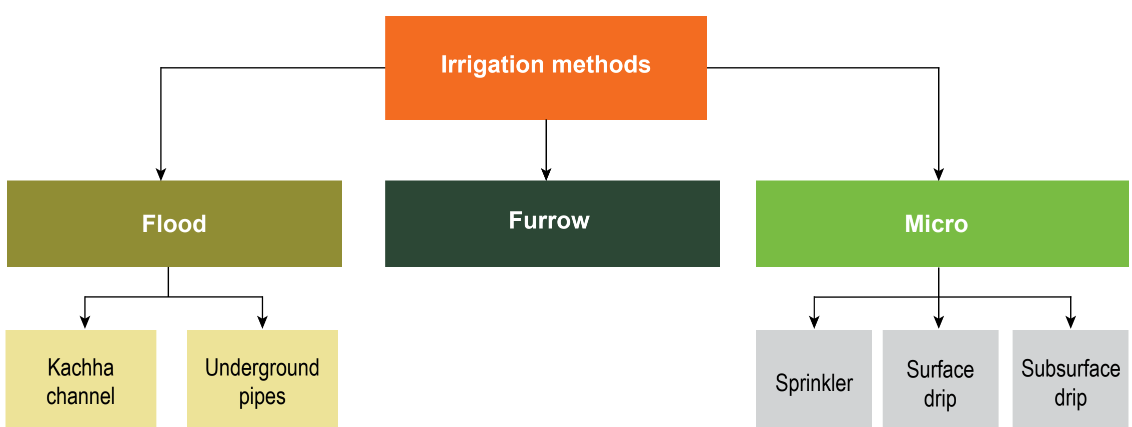
Main methods of irrigation include flood, furrow and micro (sprinkler and drip) (Fig. 4.5). Each method has its advantages and disadvantages. The most common method of irrigation is flood irrigation. Since water is scarce in many parts of the globe, it is to be applied through carefully controlled methods with minimum amount of wastage.

The suitability of the various irrigation methods depends mainly on the natural conditions (soil type, slope, climate, water availability and quality of water). Clay soils with low infiltration rates are ideally suited to surface irrigation. In sandy soils, sprinkler or drip irrigation are more suitable than surface irrigation. On loam or clay soils all three irrigation methods can be used. Sprinkler irrigation is less wasteful but a power intensive means to water crops. The most water efficient is drip irrigation. In this system water continually drips onto the root zone of plants. This has proven successful in water conservation in that comparatively small amounts are required as this resource is well targeted. Before choosing an irrigation method, an estimate must be made of the costs and benefits of the available options. On the cost side not only the construction and installation, but also the operation and maintenance cost should be taken into account. These costs should then be compared with the expected benefits (yields). It is obvious that farmers will only be interested in implementing a certain method if they consider this economically attractive. Cost/benefit analysis is, however, beyond the scope of this chapter.

4.3.1 Flood Irrigation

In flood irrigation (surface irrigation) method, water distribution is quite uneven, hence not very efficient. However, this is a simple, cheap and easy system to manage because it doesn't require any installation of irrigation mechanisms. For this reason, this irrigation practice is more favorable among farmers, especially those in developing countries. In surface irrigation system, the water is applied directly to the soil from a lined or unlined open channels and pipes located at the upper reach of the field. In flood irrigation, water

Figure 4.5. Flow chart showing different methods of irrigation



is delivered to the field by ditch or pipe and flows over the soil surface through the crops. Despite its simplicity, this irrigation type has negative effects on the crop and soil, using both water and labor inefficiently. With flooding, only 50% of the applied water is actually used by the crop. The other half is lost to evaporation, runoff and infiltration. This irrigation method can lead to leaching losses of nutrients and accumulation of salts on the soil surface.

Basin irrigation, another form of surface irrigation, requires a leveled soil surface and a narrow ridge/bunds 15 to 50 cm high on all sides of the field which will serve as the basin. The bunds prevent the water from flowing to the adjacent fields. Basin irrigation is commonly used for rice grown on flat lands or in terraces on hillsides. In general, the basin method is suitable for crops that are unaffected by standing in water for long periods (e.g. 12-24 hours). Basin irrigation is suitable for use on moderate to slow intake soils and deep-rooted crops such as maize, sorghum, wheat, or cotton. Crops that do not tolerate flooding and soils subject to crusting can be basin irrigated by furrowing or using raised bed planting. Each plot or basin has a nearly level surface. Basin size should be small if the slope of the land is steep, soil is sandy, stream size to basin is small, required depth of irrigation application is small and field preparation is done by hand or animal traction. Conversely, basin size can be large if the slope of the land is flat, soil is clay, stream size to the basin is large, required depth of the irrigation is and field preparation is mechanized. The plots may be constructed for temporary use or may be semi-permanent for repeated use as for paddy cultivation. Water is conveyed to the cluster of check basins by a system of supply channels and lateral field channels or ditches. The supply channel is aligned on the upper side (at a higher elevation) of the field for every two rows of plot.

Border irrigation is another type of flood irrigation which works on the principle of basin irrigation. Water is applied to the field through wide borders. Each strip is irrigated independently by turning in a source of water at the upper. When the advancing water reaches the lower end of the border, the irrigation supply is turned off. The area between borders, on which crops grow, and may range from 3-30 m in width. To manage border irrigation, the border surface must be leveled across its width so the water can spread uniformly across it. Borders can be 800 m or more in length and 3 – 30 m wide depending on variety of factors. Generally, border slopes should be uniform, with a minimum slope of 0.05% to provide adequate drainage. Border irrigation is suitable for deep homogeneous loam or clay soils with medium infiltration rates. Heavy, clay soils can be difficult to irrigate with border irrigation because of the long time needed to infiltrate sufficient water into the soil. Instead, basin irrigation is preferable for such soils.

4.3.2 Furrow Irrigation

Furrow irrigation is an irrigation method in which water is applied through small channels, or furrows. As water flows through the channel, it infiltrates into the soil, thus irrigating crops. The crop is usually grown on the ridges between the furrows (see section). Furrow irrigation is suitable for many crops, especially row crops and for crops that cannot stand in water for long periods (e.g. 12-24 hours). A minimum grade of 0.05% is recommended for furrows so that effective drainage can occur. Furrows should be short in sandy soils, so that water will reach the downstream end without excessive percolation losses. Shorter furrows require more attendance but can be irrigated more efficiently. Furrows can be much longer on clayey than on sandy soils. It may be more practical to make the furrow length equal to the length of the field. As compared to the other methods of surface irrigation, the furrow method is advantageous as: (i) water in the furrows contacts only less than one half of the land surface, thus reducing ponding and excessive evaporation of water, and (ii) early sowing is possible. In mechanized farming, furrows should be made as long as possible to facilitate the work and the ideal spacings for crops. Mechanical equipment will result in less work if a standard width between the furrows is maintained, even when the crops grown normally require a different planting distance. This way the spacing of the tool attachment does not need to be changed when the equipment is moved from one crop to another. However, care is needed to ensure that the standard spacings provide adequate lateral wetting on all soil types.

When there is a water shortage, it is possible to limit the amount of irrigation water applied by using ‘alternate furrow irrigation’. This involves irrigating alternate furrows rather than every furrow. Usually, crop is planted on the top of beds and irrigation water is applied in furrows. But if water is scarce, the plants may he put in the furrow itself (sunken beds), to benefit more from the limited water. As salts tend to accumulate in the highest point, a crop on saline soils should be planted away from the top of the ridge. Usually, two rows of wheat are planted at the sides or one row of maize in the centre of 67.5 cm wide raised beds.

4.3.3 Micro-irrigation systems

Micro-irrigation is the slow rate of water application at discrete locations at low pressures, and includes trickle or surface drip, subsurface drip and sprinklers. Sprinkler irrigation (overhead) and drip irrigation (localised) are the two systems that distribute water through a system of pipes usually by pumping. In the case of sprinkler irrigation, water is sprayed into the air through sprinklers so that it breaks up into small water drops which fall to the ground. With drip (or trickle) irrigation water drips onto the soil at very low rates from a system of small diameter plastic pipes fitted with outlets called emitters or drippers. Water is applied close to plants or root zone so that only part of the soil in which the roots grow is wetted. Micro-irrigation methods offer the potential for high levels of water savings because of precise, high-level management and is an extremely flexible irrigation method.

In recent past, micro- irrigation systems have become the modern standard for efficient irrigation practices for water conservation and optimal plant responses. These systems have small diameter tubing laid in the field, either on the surface or underground, with small water application devices that apply water (usually a drip or very small stream of water) directly to a plant at low pressures. Generally, their high cost and intensive management requirement currently restricts its use to relatively small field sizes. These irrigation systems can be adapted to almost any cropping situation and climatic zone. It can be used over a wide range of terrain, and areas with either very low or very high infiltration rates, salt affected soils, and poor water quality that could not be utilized with other irrigation methods. The use of micro-irrigation is increasing around the world, and it is expected to continue to be a viable irrigation method for agricultural production in the foreseeable future. With increasing demands on limited water resources and the need to minimize environmental consequences of irrigation, this technology will undoubtedly play an even more important role in the future. Micro-irrigation systems to irrigate field crops are now getting popular among the farmers in response to rising water prices and reductions in water supply. These technologies will also benefit from other precision agriculture tools such as site-specific nutrient applications.

i. Sprinkler Irrigation system

In sprinkler irrigation water is distributed through a system of pipes usually by pumping. It is then sprayed into the air through sprinklers so that it breaks up into small water drops which fall to the ground. The pump supply system, sprinklers and operating conditions must be designed to enable a uniform application of water. The lateral pipes supplying water to the sprinklers should always be laid out along the land contour whenever possible. This will minimize the pressure changes at the sprinklers and provide a uniform irrigation. The average application rate (mm/hour) from the sprinklers is always chosen to be less than the infiltration rate of the soil so that surface ponding and runoff do not occur. In CA, residue mulch can help control runoff.

Sprinkler systems require a pressurized water delivery in order to move water through the pipelines, risers and nozzles. Water is discharged under pressure in the air through a set of nozzles attached to a network of high-density polyethylene pipes. Sprinkler system design, component wear and operating conditions have a greater influence on distribution uniformity than do field conditions. Movable sprinkler systems are in use in various parts of the world. However, moving type sprinkler systems require significantly more labour than surface irrigation methods because the sprinkler lines must be moved at regular intervals to irrigate large fields.

Sprinkler irrigation system is adaptable to any farmable slope, whether uniform or undulating. In this system land leveling or terracing is not required and there is no loss of cultivable area due to channel construction. It is best suited to sandy soils with high infiltration rates although they are adaptable to most soil types and nearly all crops, except crops such as paddy. This method of irrigation is highly efficient due to uniform water distribution, crop water management can be adapted to growth stage and conditions. Fertilizers and pesticides can be applied to irrigation water. The labor requirement is lower as compared to traditional surface irrigation approaches. Yield increases of about 15-25% are reported compared to flood irrigation method. The main disadvantages associated with sprinkler systems are:

- High initial capital costs (investment in equipment - sprinklers and pipes) and high operation costs due to energy requirements for pumping and labor costs.
- Sensitivity to wind, causing evaporation losses (under high wind condition) and uneven water distribution and poor application efficiency;
- Unavoidable wetting of foliage in field crops results in increased sensitivity to diseases;
- Highly saline water (>7 millimhos/cm) causes leaf burning when temperature is higher than 35^{o} C.
- Sediments in irrigation water can cause clogging of sprinkler nozzles.
- Large labor force is needed to move pipes and sprinklers in a non-permanent system.

A typical sprinkler irrigation system consists of the following components:

a. A pump unit: Usually a centrifugal pump that takes water from the source and provides adequate pressure for delivery into the pipe system.

b. Mainline and sub mainlines: Pipes that deliver water from the pump to the laterals. They can be permanent and laid on the ground or buried, and can be moved from field to field.

c. Laterals: These deliver water from the (sub-) mainlines to the sprinklers. They are often portable but can be permanent.

d. Sprinklers: Most common are the rotary sprinklers spaced 9-24 m. apart along the lateral which is normally 5-12.5 cm in diameter.

e. Fertilizer tank or venturi system: To apply fertilizers or other chemicals.

f. Hydro cyclone filters/Sand separators: To remove particles of the size of 75 microns (200 mesh) which have a higher density than water. This equipment requires minimum maintenance and are useful for cleaning river water, canal water and tube well water which may contain sand.

A common problem with sprinkler irrigation is the large labour force needed to move the pipes and sprinklers around the field. In some places such labour may not be available and may also be costly. To overcome this problem many mobile systems have been developed such as the hose reel raingun and the centre pivot. Another system which does not need a large labour force is the drag-hose sprinkler system. To provide the full system's performance, a farmer needs to consider important parameters prior to the establishment. The sprinkler system depends not only on his financial ability but also on crop type, as well as several other aspects: field's size, slope and shape, crop production management, system type and the amount and time needed to operate the system. Average rate at which water is sprayed onto the crops is measured in mm/hour. When selecting a sprinkler system, it is important to make sure that the average application rate is less than the basic infiltration rate of the soil. In this way all the water applied will be readily absorbed by the soil and there should be no runoff. The sprinkler system capacity is the flow rate needed to irrigate an area adequately and is expressed in litres/ min / ha. The required irrigation system capacity is dependent on the peak crop water requirements during the growing season, maximum effective crop root depth, texture and infiltration rate of the soil, available water-holding capacity of the soil and pumping capacity of the well. In sprinkler irrigation, generally 2 cm depth of water is applied in each irrigation based on the soil type, type of crop and crop stages

Types of Sprinkler Irrigation Systems

The sprinkler irrigation systems may be portable, mini sprinklers, micro sprinklers, semi-solid, dragline, semi-permanent sprinklers or large volume sprinkler systems (Rain-guns). Due to the high capital investment, centre pivots, linear moves and side roll systems are used on high-value crops such as potatoes and vegetables.

(a). Self-propelled and linear move irrigation systems: These systems include center pivots that use long, single-pipe laterals moving in a circle around a central point, and linear move sprinkler irrigation systems that move in straight lines. As they travel across a field, these systems apply water just above or in the plant canopy using small sprinklers, sprayers or bubblers. Nominally, water is applied uniformly regardless of topographic, soil type or plant differences over the entire field. These systems are most suited for low-growing crops such as vegetables, alfalfa, small grains, wheat, soybeans and sugar beet as well as taller crops such as maize and sugarcane. Potential water savings using site-specific technologies are probably in the range of 15% to 30%. The ability to vary water application along the main lateral of the center pivot on the basis of position in the field would allow the field manager/farmer to address specific soil and/or slope conditions.

The self-propelled sprinkler system rotates around a central pivot point and has the lowest labor requirements of the systems being compared. It is constructed using a span of pipe connected to moveable towers. The usually self-propelled structure moves in a circular pattern and is fed with water from the pivot point at the centre of the circle. The amount of water applied is controlled by the speed of rotation. Centre pivots can be adjusted to any crop height and are particularly suited for lighter soils. They can be used on heavy soils with low infiltration able to program many features for the irrigation process. Furthermore, it is possible to install a corner attachment system (also called "end-gun") which allows irrigation of corner areas missed out by conventional centre pivot systems. A corner span generally costs about half as much as the rest of the pivot, thereby increasing the capital cost per acre.

The linear move (also called lateral move) irrigation system is built the same way as a center pivot. The main difference is that all the towers move at the same speed and in the same direction. Water is pumped into one of the ends or into the center. A more common water supply method is to drag a hose, which is connected to a buried water supply pipe through one or more hydrants, as the linear moves down the field. To gain acreage and make the transition from one side of the field to the other, some linear move systems pivot at the end of the field. The primary advantage of the linear move is that it can irrigate a large size rectangular fields. A general rule is the length of run should be about five times longer than the length of the linear move. Like center pivots, linear moves have computerized control panels that allow the operator to program speed changes and vary the amount of water applied at any location in the field, reverse the pivot and turn on auxiliary pumps at specified times. They can also be controlled remotely with smartphones and computers via cellular modems, satellite or radio communications.

The sprinklers can be mounted on top of the span pipe or on drop-tubes, which put them closer to the crop. On most center pivots, the amount of applied water is controlled by the speed of rotation. The center pivot system has many advantages including: uniformity of applied water, no human labor required, may operate at lower pressure, thus conserving energy, efficient water use, which prevents water runoff, and with a timer set, it may regulate water application and sprinkle it daily at a particular time in the day or in the evening. However, there are also some disadvantages associated with using a center pivot system. These include; high initial cost, high maintenance cost, unsuitable for irrigation of fields of rectangular or square shape, field surface should be flat, not suitable for irrigation in windy conditions.

b. Traveling big gun: The traveling big gun system uses a large capacity nozzle (1.9 to 5.1 cm in diameter) and high pressure to throw water out over the crop (53.5- to 107 m radius) as it is pulled through an alley in the field. Traveling big guns come in two main configurations: hard-hose or flexible-hose feed. With the hard-hose system, a hard polyethylene hose is wrapped on a reel mounted on a trailer. The trailer is anchored at the end or center of the field. The gun is connected to the end of the hose and pulled to the end of the field. The gun is pulled across the field by the hose wrapping up on the reel. With the flexible-hose system, the gun is mounted on a four-wheel cart. Water is supplied to the gun by a flexible hose from the main line. A winch cable on the cart pulls the cart through the field. The cable is anchored at the end of the field. Most traveling big-gun systems have their own power unit and cable winch mounted directly on the machine. Particularly adaptable to various crop heights, variable travel speeds, odd-shaped fields and rough terrain, the big gun requires a moderate initial investment, more labor and higher operating pressures than center pivots and linear moves. Rain guns are used where larger areas are to be covered in short time with one or two sprinklers. These sprinklers have a discharge ranging from 10,000 lph to 32,000 lph and radius of throw from 24 m to 36 m. These systems require high pressure and high discharge pipes and pumps to operate them.

Low cost semi-permanent sprinkler irrigation system

In semi-permanent sprinkler system, the piping network for main line and lateral lines are permanently buried with risers fitted on the lateral lines. The sprinkler nozzles are fitted on each riser pipe and can be easily shifted from one place to another to irrigate the required area in shifts as per the irrigation schedule or the crop water requirement. Portable sprinkler systems are commonly used for irrigating field crops. In portable sprinkler irrigation systems, the high density polyethylene pipes are used for mains and sub-mains which can be shifted from one place to another as per the irrigation schedule with respect to design layout. Farmers using such a portable sprinkler system are experiencing difficulty in operating them due to portable pipes and sprinkler heads are to be stored in safe place Processes involved in completion of each shift of operation are laborious and time consuming. Dismantling and emptying of pipes results water ponding causing difficulty in movement. Shifting results in huge loss of valuable operation time. A low cost hydraulically efficient semi-permanent sprinkler system has been designed and introduced to overcome the disadvantages of the conventional portable sprinkler systems with the following characteristics.

ii. Drip irrigation system

Drip, or trickle irrigation, is the system in which water is frequently and slowly applied directly on the crop root zone. Therefore, this can be a very efficient method of irrigation. The concept of this irrigation system is to irrigate only the root zone instead of the entire field surface, thus making water application efficiency maximum. In the regions of water scarcity, drip irrigation has great potential in saving large quantity of irrigation water, which may help in bringing more area under irrigation resulting in large increase in crop productivity and fertilizer use efficiency. With drip irrigation (surface and subsurface systems), water is conveyed under pressure through a pipe system to the fields, where it drips slowly onto the soil through emitters or drippers which are located close to the plants. Drip irrigation has many advantages over sprinkler or flood irrigation, including application uniformity, the ability to apply water exactly where it is needed, little water loss due to evaporation, and the potential reduction of disease and weed incidence in irrigated systems.

Drip irrigation consists of either surface or subsurface (buried) system. SSDI eliminates necessity of anchoring laterals at the beginning and removing it at the end of the season and thus laterals have longer economic life. The biggest bottle neck in adoption of surface drip irrigation in cereal based systems is labour use in frequent shifting of drip lines for different operations during crop growth. Unlike surface and sprinkler irrigation, drip irrigation only wets part of the soil root zone, which may be as, low as 30% of the volume of soil wetted by the other methods. The wetting patterns which develop from dripping water onto the soil depend on discharge and soil type. Although only part of the root zone is wetted it is still important to meet the full water needs of the crop. With a higher discharge the wetting pattern will be broader but less deep.

With drip irrigation water, applications are more frequent (usually every 1-3 days) than with other methods and this provides a very favourable high moisture level in the soil in which plants can flourish. Drip irrigation is most suitable for row crops. Generally, high value crops are considered because of the high capital costs of installing a drip system. Drip irrigation is suitable for most soils. On sandy soils higher emitter discharge rates will be needed to ensure adequate lateral wetting of the soil. One of the main problems with drip irrigation is blockage of the emitters. All emitters have very small waterways ranging from 0.2-2.0 mm in diameter and these can become blocked if the water is not clean. Thus, it is essential for irrigation water to be free of sediments. If this is not so then filtration of the irrigation water will be needed. Filtration may remove some of the materials but the problem may be complex to solve and requires an experienced engineer or consultation with the equipment dealer. Drip irrigation is particularly suitable for water of poor quality (saline water), steeply sloping or undulating land, water or labour are expensive. The drip irrigation systems have a conveyance efficiency of 100% and an application efficiency of more than 90%.

A typical drip irrigation system consists of the following components:

Pump unit, (ii) Control head, (iii). Filters and a fertiliser or nutrient tank (venturi), (iv) Mainlines and submains; (v) laterals, and (vi) Emitters or drippers, these are devices used to control the discharge from the laterals to the plants.

The control head consists of valves to control the discharge and pressure in the entire system. It may also have filters to clear the water. Common types of filters include screen filters and graded filters which remove fine material suspended in the water. Some control head units contain a fertilizer or nutrient tank. These slowly add a measured dose of fertilizer into the water during irrigation. This is one of the major advantages of drip irrigation over other methods. Mainlines, sub mains and laterals supply water from the control head into the fields. They are normally made from PVC and should be buried below ground because they easily degrade when exposed to direct solar radiation. Lateral pipes are the thin wall poly tubing commonly referred to as "drip tape". They have usually 13-32 mm diameter with and inline emitters. Drip tape is available in an assortment of wall thicknesses and emitter spacings and is relatively low cost, but also much less durable compared to the rigid poly tubing. Depending on the water source, drip tape and tubing often require filtration to limit clogging of emitters. Drip tape and poly tubing with inline emitters require a grade of 2% or less and runs of no more than 100 m for optimum distribution uniformity. Careful consideration must be given to design when setting up a drip irrigation system to optimize distribution uniformity and system function. Emitters or drippers are the devices used to control the discharge water from the lateral to the plants. They are usually spaced more than 1 m apart with emitters spaced at 30-45 cm apart. Many different emitter designs have been produced in recent years. The basis of design is to produce an emitter which will provide a specified constant discharge which does not vary much with pressure changes, and does not block easily.

A subsurface drip system is usually permanent and therefore can easily be automated. Water can be applied frequently (every day if required) with drip irrigation and this provides very favourable conditions for crop growth. Drip irrigation only wets part of the soil root zone. This is very useful when labour is scarce or expensive to hire. However, automation requires specialist skills and so this approach is unsuitable if such skills are not available. Drip Irrigation system involves dripping water onto the soil at very low rates (2-20 lph) from a system of small diameter plastic pipes filled with outlets called emitters or drippers.

SSDI system is considered economically viable option for field row crops, such as maize, rice and wheat. However, there have been very limited efforts on drip irrigation major water consuming field crops (like rice, wheat, maize) under CA. BISA-CIMMYT at Ludhiana, India is carrying out research on precision-CA in rice-wheat and maize-wheat systems. A new machine for laying sub surface drip lines has been developed at BISA, Ludhiana, which is highly economical and labour efficient. The results of first of its kind research on layering sub-surface drip with CA based rice-wheat and maize-wheat rotations have shown tremendous potential to dramatically cut down irrigation water use while producing more compared with conventional system of flood irrigation. It has been observed that irrigation WP increased by about 150 and 100% in maize and wheat, respectively (Sidhu et al., 2020). In addition, a 25% saving of fertilized N was achieved under fertigation in both maize and wheat without any yield penalty. Sandhu et al. (2019) reported that maize and wheat under surface drip irrigation with residue retention system showed significant grain yield increase of 13.7% and 23.1% compared to furrow irrigation with no residue, respectively. Surface drip irrigation with residue retention saved 88mm and 168mm of water and increased WP by 66% and 259% in wheat and maize on permanent beds compared to the conventional furrow irrigation system with residue removal, respectively.

Water Management in Rainfed Regions

Rainfed farmers are depended on rainfall to grow crops. However, rainfall is increasingly becoming unreliable leading to reduced or no yields at all. To minimize lack of water and loss of soil fertility, proper soil and water conservation measures build the foundation for sustainable rainfed farming. Keep the soil covered as much as possible and minimize the movement of water and encourage water infiltration and storage in the soil. The maximum soil moisture content, infiltration rate under mulching can substantially increase crop yields under rainfed farming. Frequent dry spells and extreme rain events are the most common characteristics of in the semi-arid tropics, which often cause water stress situation and low crop yields and high risk of crop failure. Timely and satisfactory crop establishment is a serious constraint in rainfed areas due to inadequate soil moisture at the time of sowing. If through soil moisture conservation timely sowing of crop is assured, the probability of a good crop harvest is increased. In rainfed areas, water harvesting and recycling is the only option to provide either life-saving or supplementary irrigation ensuring the stability in the productivity.

Rainwater harvesting is a technology used for collecting and storing rainwater in rainfed regions. There are three methods of rainwater harvesting: (i) in situ rainwater harvesting, collecting the rainfall on the surface where it falls and storing it in the soil; and external water harvesting, collecting run-off from rainfall over a lined (polyethylene or concrete) ponds.

In-situ rainwater harvesting refers to the method of diverting, inducing, collecting, storing and conserving local surface runoff for agricultural production. Options that (i) prolong periods of soil moisture availability include, weeding, contour planting and mulching; and (ii) promote the infiltration of water into the soil, e.g. ZT and crop residue mulch, ridging/furrowing, terracing, vegetative barriers, and planting basins. Such technologies increase the time available for infiltration and increase surface storage. Most importantly, farmers should be recommended to adopt sustainable techniques that have been evaluated for their soil types and rainfall conditions. Use of soil and water conservation practices and fertilizers are indispensable for increasing agricultural productivity, particularly in high-risk, semi-arid areas. Mulching using residue from previous crop in CA helps soil and water conservation and improving soil fertility. Mulching improves infiltration, and the soil cover provides effective protection against rain splash erosion and surface runoff. CA practices increase yields in comparison to conventional production systems in "normal" or dry years.

Suggested Readings

References

Bijay-Singh, Varinderpal-Singh and Ali, A.M. (2020). Site-specific fertilizer nitrogen management in cereals in South Asia. Sust. Agri. Rev.39, 137- 178.

Bijay-Singh, Shan, Y.H., Johnson-beeebout, S.E., Yadvinder-Singh and Buresh, R.J. (2008). Crop residue management for lowland rice-based cropping systems in Asia. Adv. Agron. 98: 118-199.

Gangwar, K.S., Singh, K.K., Sharma, S.K. and Tomar, O.K. (2006). Alternative tillage and crop residue management in wheat after rice in sandy loam soils of Indo-Gangetic plains. Soil Till. Res. 88, 242-255.

Gupta, R.K., Yadvinder-Singh, Ladha, J.K., Bijay-Singh, Singh, J., Singh, G. and Pathak, H. (2007). Yield and phosphorus transformations in a rice-wheat system with crop residue and phosphorus management. Soil Sci. Soc. Am. J. 71,1500-1507

Hobbs, P. R. and Gupta, R. (2004). Problems and challenges of no-till farming for the rice-wheat systems of the Indo-Gangetic Plains in South Asia. In: R. Lal, P. Hobbs, N. Uphoff and D.O. Hansen (eds.). Sustainable Agriculture and the Rice-Wheat System. Ohio State University and Marcel Dekker, Inc, Columbus, Ohio, and New York, USA., pp. 101-119

Ismail, I., Blevins, R.L. and Frye, W.W. (1994). Long-term no-tillage effects on soil properties and continuous corn yields. Soil Sci. Soc. Am. J. 58, 193-198.

Jat, H.S., Datta, A., Sharma, P.C., Kumar, V., Yadav, A.K., Choudhary, M., Choudhary, V., Gathala, M.K., Sharma, D.K., Jat, M.L. and Yaduvanshi, N.P. (2018). Assessing soil properties and nutrient availability under conservation agriculture practices in a reclaimed sodic soil in cereal-based systems of North-West India. Arch. Agron. Soil Sci. 64, 531-545.

Jat, M.L., Saharawat, Y.S. and Gupta, R. (2011). Conservation agriculture in cereal systems of South Asia: Nutrient management perspectives. Karnataka J. Agric. Sci. 24,100-105.

Kassam, A.H. and Friedrich, T. (2009). Perspectives on nutrient management in conservation agriculture. Invited paper, IV World Congress on Conservation Agriculture, 4–7 February 2009, New Delhi, India.

Kumar, A., Sharma, K.D. and Yadav, A. (2010). Enhancing yield and water productivity of wheat (Triticum aestivum) through furrow irrigated raised bed system in the Indo-Gangetic Plains of India. Indian J Agric. Sci. 80, 198–202.

Ladha, J.K. Yadvinder -Singh, Erenstein, O, Hardy, B. (2009). Integrated Crop and Resource Management in the rice-wheat systems of south Asia. International Rice Research Institute, Los Banos, Philippines. 395 p.

Oyeogbe, A.I., Das, T.K. and Bandyopadhyay, K.K. (2018). Agronomic productivity, nitrogen fertilizer savings and soil organic carbon in conservation agriculture: Efficient nitrogen and weed management in maize-wheat system. Arch. Agron. Soil Sci. 64, 1635-1645.

Rahman, M.A., Chikushi, J., Saffizzman, M. and Laurien, J. (2005). Rice straw mulching and nitrogen response of no-till wheat following rice in Bangladesh. Field Crops Res. 91, 71-81.

Rosegrant W.M., Cai, X. and Cline, S.A. 2002. World Water and Food to 2020: Dealing with Scarcity, International Food Policy Research Institute, Washington, D.C., USA and International Water Management Institute, Colombo, Sri Lanka.

Sandhu, O.S., Gupta, R.K., Thind, H.S., Jat, M.L., Sidhu, H.S. and Yadvinder-Singh (2019). Drip irrigation and nitrogen management for improving crop yields, nitrogen use efficiency and water productivity of maize-wheat system on permanent beds in north-west India. Agricultural Water Management 219: 19-26.

Sandhu, O.S., Gupta, R.K., Thind, H.S., Jat, M.L., Yadvinder-Singh and Sidhu, H S (2020). Evaluation of N fertilization management strategies for increasing crop yields and nitrogen use efficiency in furrow irrigated maize-wheat system under permanent raised bed planting. Archives of Agronomy and Soil Science. 66, 1312-1317.

Sharma, S., Thind, H.S., Yadvinder-Singh, Sidhu, H.S., Jat, M.L. and Parihar, C.M. (2019). Effects of crop residue retention on soil carbon pools after 6 years of rice–wheat cropping system. Environmental Earth Sciences 78: 296, https://doi.org/10.1007/s12665-019-8305-1

Sidhu, H.S., Jat, M.L.,Singh, Y., Sidhu, R.K., Gupta,N., Singh, P.,Singh, P., Jat, H.S. and Gerarde, B. (2019). Sub-surface drip fertigation with conservation agriculture in a rice-wheat system: A breakthrough for addressing water and nitrogen use efficiency. Agric. Water Manage. 216, 273–283.

Thierfelder, C. and Wall, P. C. (2011). Reducing the risk of crop failure for smallholder farmers in africa through the adoption of conservation agriculture. In: Bationo A., Waswa B., Okeyo J., Maina F., Kihara J. (eds) Innovations as key to the green revolution in Africa. Springer, Dordrecht.

Yadvinder-Singh, Gupta, R. K., Singh, J., Singh, G., Gobinder-Singh, Ladha, J. K. (2010). Placement effects on rice residue decomposition and nutrient dynamics on two soil types during wheat cropping in rice–wheat system in northwestern India. Nutr Cycl Agroecosys. 88, 471-480.

Yadvinder-Singh, Singh, M., Sidhu, H.S. Humphreys, E., Thind, H.S., Jat, M.L., Blackwell, J. and Singh, V. (2015). Nitrogen management for zero till wheat with surface retention of rice residues in north-west India. Field Crop Res.184, 183-191.

Additional suggested readings

Evans, R. G., and E. J. Sadler (2008). Methods and technologies to improve efficiency of water use, Water Resour. Res., 44, 1-15.

Jat, H.S., Sharma, P.C., Datta, A., Choudhary, M., Kakraliya, S.K., Sidhu, H.S., Gerard, B. and Jat, M.L. (2019). Re-designing irrigated intensive cereal systems through bundling precision agronomic innovations for transitioning towards agricultural sustainability in north-West India. Sci. Rep. 9, 17929.

Jensen M.E. (1983) (ed.). Design and operation of farm irrigation systems. Revised Printing. Amer. Soc. Agr. Engr. Mono. No. 3. St. Joseph, Michigan. 840 p.

Kay M. 1983 Sprinkler Irrigation: Equipment and Practice. Basford, London.

Mitchell1, J. P., Reicosky, D.C., Kueneman, E. A., Fisher, J. and Beck, D. (2019). Conservation agriculture systems. CAB Reviews 14: 1-25. (located at: http://www.cabi.org/cabreviews)

Nakayoma, F.S. and Bucks D.A. (1986) (eds). Trickle Irrigation for Crop Production: Design, Operation and Management. Elsevier, New York. 393 p.

4.4 Integrated Weed Management in Conservation Agriculture

Introduction

Weed control is crucial to achieving the potential yield gains offered by CA systems. The aim of weed management is to minimize the yield-depressing effects on crops from weed competition for light, nutrients and moisture—and not necessarily to completely eliminate all traces of weeds. In CA, minimum soil disturbance (ZT) affects weed seed bank (depth viability) and emergence, weed diversity and exposure to extreme environment (Ramesh, 2015). Herbicide use has been a valuable asset when adopting CA practices. In this context herbicides application can effectively control weeds by saving time, labour and money. Success with adoption of CA is attributed to the use of herbicides to control weeds, reduce inherent yield loss and cope with labor shortage in most countries. A plethora of herbicide availability has made CA as a significant (Cannell, 1985) means of making farming profitable and lucrative. However, judicious use of chemical weed control is essential to fulfill the goals of CA by having reducing detrimental environmental impact as well as reducing herbicide resistance development in weeds. The repeated exposure of weeds to one herbicide could lead to the possibility of herbicide resistant weed species, highlighting the need for alternative weed control strategies that are effective and accessible for smallholders adopting CA. For example, resistant to Isoproturon in weed biotypes has been reported in wheat growing areas in NW India. Similarly, the use of a single herbicide has quickly led to the emergence of glyphosate-resistant weeds. Integrated weed management (IWM) through cultural, mechanical and judicious use of herbicides is important for the success of CA. For weed management, all options should be explored including physical, biological and chemical control.

Maintaining crop residues is a critical aspect of CA and has the effect of impeding weed germination in the subsequent crop. Availability, quality, price and precision of application are all issues that will be disincentives to their effective use of herbicides, besides the question of whether herbicides should even be an option in smallholder agriculture for weed management. However, a judicious combination of mechanical, biological and chemical weed control methods may be an appropriate response in many situations, and effective weed control is one of the key ingredients of successful CA. Knapsack sprayers for herbicide spray can be mounted on a wheeled chassis, fitted with a multi-nozzle boom and hand-pulled, so partially removing the operator from the risk of contamination. Larger capacity boom sprayers are manufactured for animal traction.

The Challenge of Weed Management in Conservation Agriculture

Major challenge associated with CA implementation in the early years of conversion is the increase in weed pressure as a result of eliminating tillage as a weed control mechanism. Consequently, finding appropriate weed management strategies is crucial for maintaining adequate yields and compensating for additional labor demands in the first years after CA implementation, thereby ensuring continued use of CA practices thereafter. Generally, CA systems favor perennial weeds and species that can successfully germinate on the soil surface such as annual grasses. Literature worldwide has proved the dominance of grassy perennial weeds under CA, as species shifts and adaptation might occur when an environment changes over time (Martinez-Ghersa et al., 2000). The goals of succession management would involve reducing populations of the species most likely to proliferate under CA since changes in weed communities are inevitable and an intrinsic consequence of growing crops over time (Owen, 2008) as the physical movement of soil is restricted to minimum for crop production (Price et al., 2011).

An increase in weed seed bank can occur due to greater survival of weeds when the farmers adopt the CA. Weed management during transition to CA systems is crucial. The initially large number of weeds immediately following transition to CA should not be discouraging, as it can be a transitory phenomenon. It can be expected that a greater amount of herbicide might be necessary in the first years of transitioning.

Weed infestations are claimed to decrease with time, after a transition period of about 2 to 3 years, resulting with the subsequent reduction in herbicide use when the three CA principles are followed. However, the majority of farmers have only adopted those CA principles that fit into their farming systems. Weed problems are more likely to occur if only one principle of CA practice is utilized. However, there are reports where changing to ZT in rotations did not result in an increase in perennial weeds. This emphasizes the importance of crop rotation in weed management, especially in CA systems.

Crop residue mulch will inhibit weed seed germination, and growth due to light exclusion and soil surface insulation leading to reduced weed seed viability and therefore reduced weed numbers (Fig. 4.6). Studies from North-West India, showed that ZT lowered the infestation of canary grass (*Phalaris minor* L) in wheat due to less soil disturbance as a result weed seeds present in lower soil layer fail to germinate due to mechanical impedance, which is the main threat to the sustainability of wheat production under rice-wheat system. Similarly, *Chenopodium album* seedling emergence declined significantly due to ZT wheat sowing during first year; in subsequent years, population of *C. album* was completely eliminated. Surface residues as mulch, inhibit emergence of *P. minor, Chenopodium album*, and *R. dentatus* by up to 88% compared to without residue mulch. However, in some cases, the maintenance of crop residue reduced herbicide efficacy. Studies have shown that the weed suppression provided by surface residue more than compensates for reduced herbicide contact with weeds.

Actually, the challenge of using herbicides for weed control in CA is further complicated by the fact that mechanical incorporation of herbicides into the soil is not possible with no-tillage systems, which limits herbicide options to only post-emergence. Weed control under CA has been linked to increased herbicide use, but concerns about herbicide resistance, access to chemicals, and environmental impacts highlight the need for alternative weed control strategies accessible for smallholders. Clearly, unless weed management is sustainably addressed in CA, particularly in the initial years, weed pressure, weed resistance and inherent crop yield losses may deter farmers from adopting CA practices. However, to support adoption of CA, weed management challenges should be anticipated and addressed with practical solutions, particularly for small-scale farmers, because they are vulnerable and may quickly get trapped in a vicious weed cycle that goes along with poverty and migration.

Weeding with hoes or with equipment pulled by animals or tractors is more difficult in CA because of the crop residues or mulch on

Figure 4.6. Weed growth in conventional till (L) and CA maize (R)

the ground. Farmers may be reluctant to use herbicides because of the expense, or because they do not have the right equipment. However, access to herbicides could be increased through providing subsidies. Additionally, governments could encourage local production of cheap generic versions of non-patented herbicides like glyphosate, which would improve access. For such an initiative to be successful, herbicide quality and safety would need to be guaranteed through the creation of testing laboratories and enforced quality standards. Farmers in semi-arid rainfed regions contend with the additional challenge of low biomass production and, often, competition with livestock enterprises, which limit the potential weed-suppressing benefits of mulch and living cover crops. Mechanical weeding by human labor power (hoeing, scraping, rogueing, uprooting) is a laborious undertaking. Furthermore, there is shortage of labor for weeding (and, often, primary land preparation). Fortunately, there are options that can reduce weed pressure and incorporate the idea that weed management, rather than total weed elimination. Farmers may be reluctant to use herbicides because of the expense, or because they do not have the right equipment. The use of herbicide-tolerant crops (soybeans, maize, cotton, canola) reduced weed problems associated in many countries where CA is used. The availability of such crops with resistance to a non-selective herbicide like glyphosate has provided the means for effective post-emergent herbicide control of a broad spectrum of weed species while reducing labour demands and repeated herbicide applications. Completely eliminating weed seed production is unrealistic, but if seed input is controlled, the viable weed seedbank stock will reduce considerably in CA systems. In CA systems, preventing weed establishment may be more crucial in preventing weed seed production than in tilled systems. Prevention of weed seed-set is perhaps one of the most powerful mechanisms of weed control offered by rotations.

4.4.1 Weed Management Strategies

Weed management is believed to be the main constraint to the widespread adoption of CA, because weeds compete with the crop for nutrients, water light and space resulting in yield reduction. It is important to control weeds at the right time, before they become a problem. Weed control without tillage is more complicated and requires much more knowledge. Development of herbicides made it possible to eliminate the requirement of tillage for weed control and made the possibility of successful adoption of CA system. The principles of CA, particularly crop rotation and surface residue retention, are in themselves methods of weed control. CA reduces weed numbers in several ways: (i) It disturbs the soil less, so brings fewer buried weed seeds to the surface where they can germinate; (ii) The residue cover on the soil smothers weeds and prevents them from growing; and (iii) Changing crop rotation allows control of weeds with different emergence seasons, preventing a particular type of weed from repeatedly completing its life cycle. The use of herbicides is sometimes a limitation with smallholder farming systems. However, a judicious combination of mechanical, biological and chemical weed control methods may be an appropriate option in many situations and effective weed control is one of the key ingredients of successful CA. Additional options for weed control in CA systems may include selecting new varieties with more competitive crop canopies; altering crop planting dates, planting densities, row-spacing and fertilizer placement. Using weed seed free clean seed, keeping irrigation channels and bunds free from weeds are simple but effective tools for reducing these types of weed seed bank. Reducing the weed seed bank is particularly important during the first 2–3 years after transition to CA, as the seed bank in the soil will likely be well filled initially. The year-round weed control is needed to deplete the weeds from soil. Late season weed seed harvest and destruction are vital to successful weed control in CA.

There is no single solution can solve all weed control challenges under current CA systems; success of weed control strategies is largely contingent upon site-specific conditions, including soil type, dominant weed species, and socioeconomic factors. Nevertheless, successful weed control is not possible without farmers maintaining CA principles and practices in the long term.

In order to limit over-reliance on herbicides for weed control under CA systems smallholder farmers, numerous alternative methods have been proposed. Preventive weed management focuses on preventing the introduction of new or additional weed populations and reducing the overall emergence and establishment of weeds in the field. It encompasses all measures that curb the introduction and spread of weeds. These methods are cheap and avoid disturbing the soil. The various weed management practices can be grouped into three broad categories.

i. Manual and mechanical weed control

Manually-powered mechanical weed control options include shallow scraping with sharp hand-hoes, hand pulling and slashing are the most common weed management strategies for smallholder farmers. As holdings become larger, then animal traction and tractor power can be used for weed control (e,g, knife roller). In order to comply with the principles of CA, farmers using hand hoes for weed control must use the tool for shallowly scraping the soil surface to remove weeds, rather than employing a digging motion, which may be more time consuming. Manual weed control is time consuming and labour intensive, but does not require extensive knowledge nor is it risky. Tall weeds growing in the main crop can be effectively controlled and prevented from producing seeds by a weed header. On larger holdings, animal traction and tractor power can be used for knife rolling, which crushes the weeds and cover crops prior to direct planting. Insufficient labor availability to suppress weed populations is a major challenge for adopting CA technologies. High-intensity weeding is challenging to labor- and resource-constrained famers. Farmers can use an animal- or tractor-drawn weeder, plant the crops in rows with the same spacing as the cultivator blades. Weeding by draught animal or tractor power is quicker and easier than by hand. A drawback of mechanical cultivators is their inefficiency and impracticality when large quantities of plant residues are present.

ii. Biological control

Biological control, by means of keeping the soil surface covered and weeds are controlled by competition. In CA, surface cover is achieved with residue mulch and cover crops under sown in the main crop before harvest and covering the soil until the establishment of main crop. The use of cover crops is increasing in CA systems globally and has vast potential for smallholder systems where they can offer important food and forage production possibilities as well as reducing weed pressure and protecting the soil from water and wind erosion.

iii. Chemical weed control

Chemical weed control has often been an important step towards farmer adoption of CA due to the significant reduction in labour requirement when compared with manual mechanical control and the huge drudgery associated with mechanical weeding which is almost entirely done by women, the elderly and adolescents. A major cause of dis-adoption of CA in African countries is increased labour demand for weeding in situations where herbicides are not used (Arslan et al., 2014; Giller et al., 2009; Nyanga et al., 2012). This is because poorer farmers reportedly cannot afford herbicides, or herbicides are not available. Increasing labour shortage and cost of labour however, makes chemical weed control an attractive alternative for small farmers. Chemical weed control is preferred over manual and mechanical weed control because of following reasons:

1. Sometimes weeds resemble morphologically to crop plants and are very difficult to distinguish till flowering. eg. *Phalaris minor* in wheat and *Echinochloa spp.* in rice.
2. Manual or mechanical weeding is not possible during rainy season due to continuous rains and soil conditions are not conducive for hoeing.
3. Weeds escape the removal within rows.
4. Sometimes in close spaced crops or in broadcast sowing, manual weed control is not possible and necessitates the use of herbicides.
5. Manual weeding is cumbersome, costly and time consuming.
6. Herbicides are quick and easy to apply, and do not disturb the soil.

The development of glyphosate tolerant crops and the use of pre and post-harvest glyphosate have essentially eliminated the perennial weed disadvantage for CA. The herbicides commonly used for weed control, as a replacement for primary tillage in CA, include glyphosate

[N- (phosphonomethyl) glycine] and paraquat (1,10-dimethyl-4,40-bipyridinium) are considered crucial for successful weed control. The usage of non selective and non residual herbicides (glyphosate, glufosinate and paraquat) during the fallow period in between crops is crucial for successful weed control in CA systems. Moreover, if these herbicides are applied as tank mix application with soil residual herbicides such as pendimethalin (wheat, soybean, pulses) or atrazine (maize) as pre-planting option will further improve the weed control. The usage of non selective and non residual herbicides (glyphosate, glufosinate and paraquat) during the fallow period in between crops is crucial for successful weed control in CA systems. Moreover, if these herbicides are applied as tank mix application with soil residual herbicides such as pendimethalin (wheat, soybean, pulses) or atrazine (maize) as pre-planting option will further improve the weed control. Factors such as weed density, dominant species, and farmer knowledge would need to be considered when establishing an herbicide application program. In the absence of adequate labour as well as tillage options, intensive herbicide use would be necessary during the first 3 or 4 years. Thereafter, weeds could be more effectively controlled using mechanical or cultural methods. Herbicide could be foliar applied or soil applied. Based on the time of application, herbicides are classified into pre-emergence and post-emergence herbicides; and base on herbicide movement in plants, there are systemic and non-systemic (contact) herbicides. Selectivity of herbicides determines their compatibility with crop and the type of weed they control. The availability of herbicides, their quality and price, and precision of application are all potential disincentives in smallholder farming systems.

In CA, pre-emergence herbicides are generally less effective in controlling weeds due to interception of herbicides by the surface retained residue and ultimately the less herbicide reaches the sol surface to inhibit the emergence of weeds. However, it will depend on the nature of crop residue, its quantity and nature of the herbicide molecule as well as the management practices. By modifying the application timing (pre planting just before sowing or post-emergence before irrigation) and spray technology (high volume spray) can improve herbicide efficacy in CA. However, the residue cover in combination with post-emergence herbicides will improve the weed management in long term. Therefore, farmer adopting CA will primarily be dependent upon the post-emergent applications. However, another advantage with the system is that we can use non-selective herbicides to knockout weed before seeding. In addition, if weeds are managed effectively for initial two to three years then in long term the system have fewer weed problems due to more predation by birds and lesser seed bank. Changing herbicides from year to year or using different herbicides within the season (pre- and post-emergence) can prevent the build-up of tolerant/resistant weed species. Chemical weed control is quick and effective, but herbicides have to be applied properly. Farmers need to be trained in their safe use to prevent improper application that may damage crops, reduce herbicide-resistance, and avoid negative environmental consequences. The person applying the chemical needs should have specialized knowledge of herbicide products, the weeds they control and the crops they are used for, their toxicity and how to handle them, the conditions under which they work best. Similarly, application methods and rates, types of equipment and its calibration, types of nozzles, use of protective clothing etc. are also important. In CA, there are some differences in the type and timing of herbicides used compared to conventional plough tillage.

Some of the herbicides require surfactants for better efficacy. Surfactants help in better penetration and spread over leaf surface by reducing the surface tension thereby increasing the contact area and the weed control efficiency. Some times adjuvants are added to increase the herbicide efficiency. The adjuvants are chemicals having no herbicidal activity but when added to herbicide enhances the herbicide activity. These are mostly added at the time of formulation of herbicides. Certain fertilizer adjuvant like ammonium sulphate when added to herbicide spray solution increases the absorption and translocation and ultimately the herbicide efficacy.

i. Chemical weed management in ZT wheat

Weeds such as *P. minor A. ludoviciana* and *Poa annua*, and many broad-leaved weeds in ZT wheat can be controlled effectively with the application of isoporturon, at 600-1000 g/ha, depending on soil type, before or after first irrigation in ZT wheat. In areas, where *P. minor* has evolved resistance to isoproturon, application of pinoxaden 50 g or sulfosulfuron 25 g or clodinafop 60 g or fenoxaprop 100 g/ha at 30-35 DAS of wheat provided effective control of *P. minor* and *A. ludoviciana* in ZT wheat. In case of broad-leaved weeds like *C. album, Anagallis arvensis, Medicago denticulata, Coronopus didymus, R. dentatus etc*., 2,4-D sodium salt or 2,4-D ethyl ester at 400-500 g/ha at 35-45 days after sowing (DAS) when wheat is sown at normal time and at 45-55 DAS in late sown crop are effective. Metsulfuron 5 g/ha at 30-35 DAS provides effective control of *R. spinosus* but not effective against Lathyrus aphaca. However for control of diverse broadleaved weed flora ready or tank mixture of metsulfuron and carfentrazone should be used. along with other broad-leaved weeds, as 2,4-D do not control this weed. Carfentrazone-ethyl at 20 g/ha at 20-25 DAS provides effective control of many broad-leaved weeds including *Malva parviflora* and *R. spinosus*. In fields where both grass and broad-leaved weeds are present, one post-emergence application of sulfosulfuron + metsulfuron at 32 g, mesosulfuron + iodosulfuron at 12+24 g, clodinafop + metribuzin at 60+210 g or tank-mixture of clodinafop 60 g + metsulfuron 4 g/ha at 30- 35 DAS is effective. In fields having the problem of multiple herbicide resistant P. minor or wild oat (resistant to clodinafop and sulfosulfuron), pyroxasulfone at 127.5 g/ha should be used as pre-plant or pre-emergence or early post-emergence application in wheat except durum wheat. In fields, where rapeseed and mustard crop is sown with wheat, use of only clodinafop, pinoxaden and fenoxaprop is advisable. Do not use the same herbicide along with other weed management practices year after year as it leads to the evolution of resistance in weeds as well as shift in weed flora.

ii. Chemical Weed management in dry seeded rice

Availability and rising cost of labour for conventional practice of transplanting rice has led to adoption of dry seeded rice (DSR) as an alternative to rice transplanting. Moreover, DSR system is suited to adoption of CA in rice-wheat system across North-West India and other parts of the world. Weeds are the important concern in DSR. Yield losses caused by uncontrolled weeds in rice were up to 98% in ZT DSR. Successful cultivation of DSR requires intensive use of herbicides. A variety of herbicides have been screened and found effective for preplant/ burndown, preemergence, and postemergence weed control in dry direct drill-seeded rice systems, including under zero-tillage conditions. Weeds can be managed in DSR by applying pre-emergence herbicide pendinmethalin (1 kg a.i. / ha) and post emergence herbicides bispyribac sodium (25 g ha^{-1}) and pyrozosulfuron (20 g ha^{-1}). The perennial weeds can be controlled by spraying glyphosate (1.25 kg ha^{-1}) before seeding (Table 4.6). Application of two or more compatible herbicides used as a tank mixture are more effective to broaden the spectrum of weeds control including grasses, broadleaves, and sedges than a single application in direct seed rice (Ahmed and Chauhan, 2014). Detailed list of herbicides along with rate and time of application for controlling weeds in DSR is included in table 4.6.

Table 4.6. List of herbicides along with rate and time of application for weed control in DSR

Herbicide	Dose (g/ha)	Application time	Weeds controlled
2,4-D	500	Post emergence	Broad leaved weeds and sedges
Fenoxaprop-p-ethyl	60-70	Post-emergence	Grasses
Metsulfuron methyl + Chlorimuron ethyl (Almix)	4	Post-emergence	Broad leaved weeds and sedges
Ethoxysulfuron	15	Post emergence	Broad leaved weeds
Propanil	3000	Post-emergence	Grasses and broad leave weeds
Butanil (Butachlor + propanil)	840 + 840	Post emergence	Grasses, broad leaved weeds and sedges
Bispyribac-Na	25	Post emergence	-do-
Penoxsulam	25	Post emergence	-do-
Azimsulfuron	25	Post emergence	-do-

iii. Chemical weed control in other crops

Maize is recognized as one of the most productive and profitable diversification options by the smallholder farmers in the rice-based cropping systems. Weed management is one of the key challenges due to very high weed pressure and seed bank in maize. Use of herbicides in different ways of combinations would make effective chemical weed control in maize. Optimizing the use of pre-plant/sowing and pre-emergence herbicides can effectively knock down the existing weeds and control the weeds before economic threshold level in both conventional and CA systems. The efficient and right use of herbicides in different ways: such as sequential use of pre-plant, pre and post-emergence and their combination may be the best way for effective control of weeds in view of economics and efficacy in maize production. When herbicides are applied immediately or 1-4 days after sowing, before weed seed emergence, are known as pre-emergence herbicides. Pendimethalin and atrazine (1.0 kg ha^{-1}) can be applied as pre-emergence to get maximum weed control efficiency and crop selectivity by decreasing the weed population and increased the ZT maize grain yield over the weedy check field. A field study showed that pre-emergence application of atrazine at 1.0 kg ha^{-1} + paraquat 0.60 kg ha^{-1}, or by oxyfluorfen 0.150 kg ha^{-1} + paraquat 0.60 kg ha^{-1} effectively control weeds in ZT maize (Yakadri et al., 2015). Application of herbicides after the emergence of maize and weed are well-known as post-emergence herbicides. Generally, post-emergence herbicides are sprayed in standing crop targeting weeds canopy by using the sprayer equipment. The most popular/well-known herbicides which have been found to be effective when applied as a post-emergence for effectively control of weeds in CA-based maize system are Atrazine, Tembotrione, Halosulfuron methyl, Tembotrione + Atrazine, Halosulfuron methyl + Atrazine (Fazal et al., 2009). The post-emergence herbicides, the mixture of tembotrione + atrazine was more effective in controlling all classes of weed flora at 40 and 60 DAS. Tembotrione alone also showed good control of grasses and broad-leaved weeds. Similarly, Chhokar et al 2020 reported the season long efefctive weed control in maize with tank mix application of HPPD herbicides (mesotrione, tembotrione and topramezone) with atrazine at 15-20 days after seeding of maize.

Different herbicides recommended for effective weed control in maize, pulses and oilseeds are listed below:

Crop	Herbicides
Maize	2,4-D, Pendimethalin, Atrazine, Mesotrione, Tembotrione, Topramezone, Halosuluron, Flumioxazine
Pulses	Pendimethalin, Fenoxaprop, Quizalofop ethyl, Imazethapyr, Oxyflourfen
Oilseed	Pendimethalin, Fenoxaprop, Quizalofop ethyl

4.4.2 Calibration of Sprayers

Herbicide needs to be applied uniformly across the field. Areas of over or under application will result in undesirable results. Potential problems include crop injury, lack of weed control and rotational crop injury by herbicides with residual herbicides. Therefore, for achieving the desired result of proper calibration is a must. The main aim of the spray calibration is to apply desired quantity of a herbicide uniformly over the targeted area. Calibration helps in determining the quantity of water and herbicide needed for proper spraying. It is, therefore, essential that sprayers are well calibrated. Sprayers must have nozzles in good condition and must be operated at the correct height above the target (whether soil surface, crop or weeds). Failure to pay attention to these working practices can lead to incomplete (or excessive) coverage, resulting in inefficient and ineffective spraying and waste of agrochemicals. The most common methods of chemical application are by knapsack and boom-sprayers, and herbicide roller. Boom-sprays provide a relatively cheap and effective method of applying both herbicides and insecticides. Before applying any chemical read the label and select the application rate. Check that all nozzles on the boom are the same type and size.

The easiest way to calibrate a sprayer is to spray a known area and measure the volume of the solution used for spraying from the tank. Based on the water needed to cover an area, the quantity of water needed for spraying one ha area can be worked out. The number of spray tank required to cover an area of one ha can be worked out by dividing the water needed to cover an area by the capacity of the spray tank. Walking or moving speed, nozzle capacity and pressure influence sprayer calibration. Spray output, moving speed and spray swath width need to be determined for calibration. Two important criteria for effective spray operation are the height of the boom (or nozzle) above the target and the uniformity of distribution. The fans from individual nozzles should overlap at the height of the target to achieve uniform coverage. The uniformity of the spray can be estimated visually by spraying on to a dry concrete track and watching for differential drying. Spray output can be measured by running the sprayer over a measured track, measuring the volume of spray delivered and calculating the area covered. The application rate can then be calculated as follows:

Spray volume delivered along length of test track (L) × 10,000 divided by length of test track (L, m) x width of work (m) =litres of spray/ha

The width of work on a multi-nozzle sprayer is the distance between the nozzles multiplied by the distance between them.

Calibration of knapsack sprayer: In order to calibrate the knapsack sprayer, fill its tank with known volume of water. Mark out an area of, say 50 m², and spray it at normal working speed and height. Measure the total volume of spray delivered. and repeat the test at least three times and make average delivery. Calculate the application rate per hectare by multiplying the applied volume by 200. Then calculate the amount of chemical to be added to each tank. For example, if 8 sprayers of 25 litres (i.e. 200 litres/ ha) are applied and it is necessary to apply 4 litres of agrochemical per hectare, each tankful must contain 0.5 litres of chemical.

Calibration of boom sprayer: There are several methods for calibrating boom-sprays. However, whichever method is chosen, it will be a waste of time and money if accurate measurements are not taken. The following simple accurate method can be used for calibrating boom-spray:

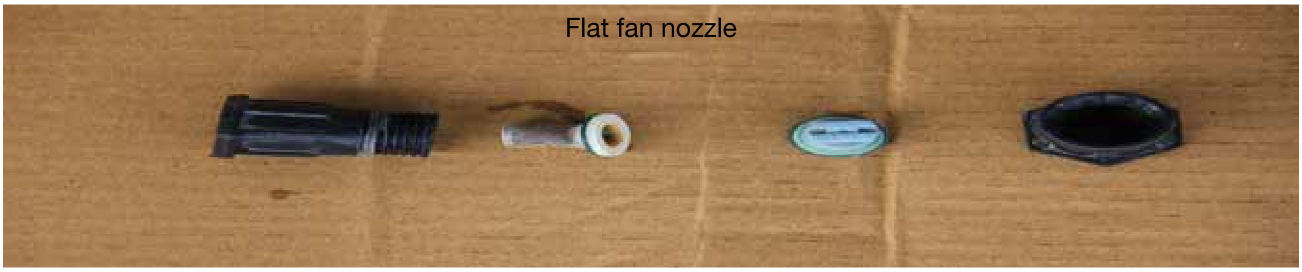
1. Set the pressure at the required level.
2. Using a measuring cylinder, measure the output (in mL) per nozzle for 60 seconds. Any nozzle that varies by more than 10% from the average should be replaced. Note the average output (mL).
3. Measure a distance of 100 m in the field to be sprayed. Record the time in seconds (T secs) that it takes to travel this distance (average of at least three runs) using the same tractor in the same gear and with the same engine speed as you intend to use when spraying.
4. Measure the distance (in cm) between nozzles (D, cm). Output (L/ha) can now be calculated using the following formula:
5. Spray output (L/ha)= (Nozzle output, ml/ min) x 60 / (nozzle spacing in cm x speed of spraying, in km/h)
6. Example: Assume the following measurements: Output/nozzle/minute = 700 mL Time to travel 100 m = 36 secs (10 km/hr) Distance between nozzles = 50 cm Output in L/ha will be = (700 x 60)/(50 x 10) = 84 L/ha

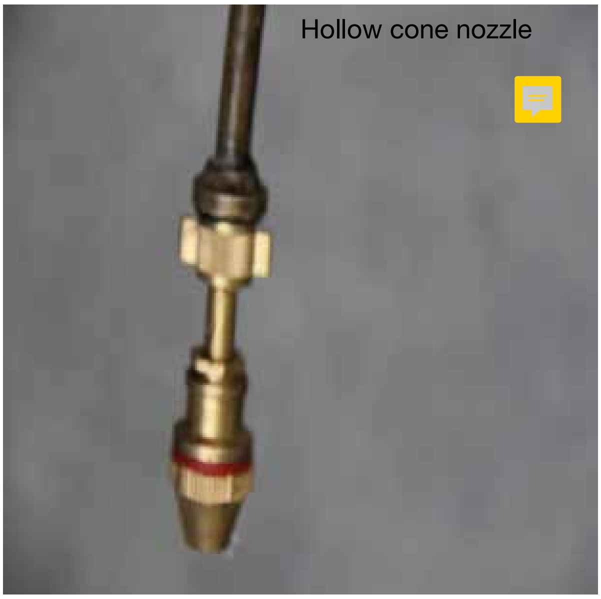
4.4.3 Type of Nozzles and Spray Tips

The most important but usually neglected aspect of the spraying system is nozzles. The nozzle performs four basic functions: It atomizes the liquid into droplets; disperses the droplets in the specific pattern; meters liquid at a certain flow rate and provides hydraulic momentum. Nozzle consists of a spray tip, strainer, and a nozzle body and a cap. The flow and distribution of the spray output is determined by the spray tip. Spray tips is the most important aspect of the nozzle. It can be flat fan, even fan, flood (cut), cone (variable or hollow).

The nozzles vary in their capacity with regard to spray output. If all the other conditions are kept constant, spray output will be dependent on the nozzle capacity. The nozzle capacity depends on the size of the nozzle and they are available with a capacity of 700, 800, 900 and 1000 ml/min. Low capacity nozzles are generally used in multi nozzle boom spraying. A large orifice creates the coarse droplets. The spray swath will depend on the type of nozzle and number of nozzles on the boom as well as the height of nozzle from the ground. The height of nozzle should be kept at about 30-45 cm above the soil surface so that there are not excessive overlapping as well as uncovered area. The boom should be kept at constant height and moved at constant speed.

a. **Flat fan nozzle**: Flat fan nozzle forms a narrow, elliptical, inverted V pattern.


Flat fan nozzle


Hollow cone nozzle


Flood jet nozzle


Two-nozzle boom

Herbicide concentration is heavier in the centre and tapers towards the outer edge. Flat fan nozzles are mainly standard flat fan nozzles and even flat fan nozzles. The flat fan nozzle helps in uniform and rapid application of herbicides. When spray is done using a single nozzle then it is desirable to use even fan nozzle because spray pattern is uniform from one end to the other end. Flat fan nozzles should be used for multiple nozzle booms. Here spray concentration is higher in the middle and lower on both edges. So, it is desirable to overlap about 30% spray pattern for uniform application of herbicides and also nozzles should be offset by 10-20^{o}.to avoid the hindrance of spray pattern of one nozzle by other.

b. **Flood jet or Cut and cone nozzles**: Cut nozzles are widely used by the Indian farmers. Here, the herbicide concentration is heavier towards the outer edge. Cone nozzles either variable or hollow are generally used for application of fungicides and insecticides. It is used for low volume spray application and produces small droplets at moderate to high pressures (500-2000 kPa).

To prevent clogging of nozzles strainers having fine mesh screens are preferred. Before starting spraying, nozzle tip, strainer and nozzle body should be thoroughly rinsed with water. Never use pin/wire to remove particles from the spray tip because it will damage the spray tip. To have uniform herbicide spray pattern it is advisable to remove worn out and damaged spray tip. For efficient and accurate application of herbicides multiple nozzle booms are used. It should be ensured that all the nozzles are of same capacity.

Two, three or four nozzles can be fitted on a boom for knapsack sprayer. The spray pattern of nozzles on boom depend on spray tip angle and height of the boom from the ground. Generally, spacing is wider for larger spray angles keeping height constant. Mostly, nozzles are available in 80° or 110° angles for these angles, spacing of flat fan nozzles is kept at 45-50 and 70-75 cm at boom height of 45-50 cm. The spacing of nozzles is kept in such a manner that spray pattern of two adjacent nozzles overlap (30%) because spray of each flat fan nozzle is light on both edges and concentrated in the middle. Similarly, one boom pass should be overlapped by 30% area of the adjacent nozzles to have uniform herbicide application. Boom height can be checked by spraying on the bare surface and spray height should be chosen where the coverage is uniform. This height should be above the target and not the ground when spraying is done. The effective swath of a boom is determined by multiplying the number of nozzles with their spacing. Suppose, if three nozzles are spaced at 50 cm then swath will be 1.5 m.

Precautions during field application of herbicides and pesticides

Herbicides are chemical compounds used to control weed species but could also phytotoxic to crops and harmful to animals through entering direct or indirect in food chain. Therefore, herbicides should be carefully selected considering the toxicity, residual persistence in soil and water bodies as well as cropping systems. The herbicide/pesticide residual persistence can affect the succeeding crops in a crop rotation and also the runoff of rain water from crop fields to water bodies which may cause the lethal and hazardous to water organism and human beings. There is a certain risk of intoxication to directly exposed workers, as well as applied crops workers if precaution measures are not properly followed. Therefore, it is an important to must follow the safety and health management guidelines while working and using the herbicide/pesticide at all steps.

Check condition of hoses, filters, clamps, pump, tank, valves, nozzles--everything the spray passes through is a checkpoint for potential problems, such as leaks, clogs, cracks, and poor seals. Check for nozzle wear; nozzles with flow greater than 10% of a new nozzle should be replaced. Use of clean water of good quality for dilution. Poor quality water will adversely affect the performance of the chemical. Before calibrating check that pump is operational and the filters are the correct size and are clean. Check hoses, nozzles and the tank are clean and there are no leaking connections. If a low amount of water is being used, nozzle angles should be increased. If the amount of water used is more than 50 L/ha, use 80 º or 100 º nozzles. When applying herbicides to weeds, a 110 º nozzle is preferred as the smaller droplets are less prone to dripping off leaves. Nozzle tips are made of various materials and the rate of wear varies accordingly. A brass tip may only last 5 to 10 hours when using wettable powders, whereas harder tips may last over 50 hours using the same product. All nozzles should be calibrated every 50 hours, and where there are variations of more than 10% from the average, they should be replaced. Fan type nozzles are recommended for herbicides and cone type nozzles for insecticides.

Conclusions

The CA-based crop management techniques may face the major concern of weed management initially. Therefore, proper weed management is considered one of the most important prerequisites in CA-based crop cultivation systems to ensure high crop yields. High weed pressure, lowers the economic returns and, in extreme cases complete failure of the crop. Hence, judicious weed management in CA system is a critical factor for securing and sustaining food security. Weed species shifts and losses in crop yield as a result of increased weed density have been cited as the major hurdles to the widespread adoption of CA. Without effective weed management and control strategies, successful adoption of CA in smallholder farming systems in most countries of Africa is rather unlikely. This is because maximum benefits are obtained when the three pillars of CA - minimum tillage, permanent soil cover and crop rotation - are applied simultaneously and in conjunction with good agronomic management including weeds. The reported adverse weed changes have been assigned to partial adoption of CA by smallholder farmers and argue that under recommended CA practices weed pressure and related management begin to decline from the third year of CA adoption. Weed control, although a major challenge in the initial years of conversion to CA, can be managed by a suite of options in reach of smallholder farmers. The weed challenges in CA requires that its inbuilt weed management component (cover crop, crop residue mulching and crop rotation) be complemented with other weed management strategies without compromising its principles. Adoption of any compatible physical, biological or chemical weed management strategy to the existing cultural weed management of CA by the smallholder famers fulfils the multiple tactics of integrated weed management. A combination of strategies that take local conditions and resources into account is considered necessary. Because soil moisture and weed composition are likely to change over the years following CA adoption, the success of certain strategies may also change over time. It is important to use the right amounts of chemicals, mix them with clean water, and handle them safely. Training is important on how to use the sprayers is them the right way. Hand weeding proves uneconomical due to be increasing labour wages as well as lack of labour. To address the weed management problems in CA-based production systems, chemical weed control is a potential means for controlling weeds and more economical compared to hand weeding. Howewver, poor farmers reportedly cannot afford herbicides, or herbicides are not available. Where herbicides are subsidized farmers often use them. Policy makers and service providers may consider an enabling environment for improved access to the various options available for weed control. As an important pre-requisite, extension agents must be trained in herbicide use and application in order to show farmers how to optimize input use and limit potential negative impacts on the environment and human health by using applicators and protective clothing.

References

Ahmed, S. and Chauhan, B.S. (2014). Performance of different herbicides in dry-seeded rice in Bangladesh. The Scientific World J. Article ID 729418; 14 p. DOI.org/10.1155/2014/729418

Arslan, A., McCarthy, N., Lipper, L., Asfaw, S., Cattaneo, A. and Kokwe, A. (2014). Food security and adaptation impacts of potential climate smart agricultural practices in Zambia. ESA Working Paper No. 14-13. Rome, FAO.

Baudron, F., Tittonell, P., Corbeels, M., Letourmy, P., & Giller, K. E. (2011). Comparative performance of conservation agriculture and current smallholder farming practices in semi-arid Zimbabwe. Field Crops Res.132, 117–128.

Chhokar, R.S., Sharma, R.K., Gill, S.C., and Singh, G.P. (2020). Tank-mix application of p-hydroxyphenylpyruvate dioxygenase (HPPD) inhibiting herbicide (mesotrione, tembotrione or topramezone) with atrazine improves weed control in maize (*Zea mays* L.). J. Res. Weed Sci. 3, 556-581.

Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Res. 114, 23-34.

Malik, R.K., Kumar, V., Yadav, A. and McDonald, A. (2014) Conservation agriculture and weed management in South Asia: perspective and development. Indian J Weed Sci 46, 31-35

Kaumbutho, P. and Kienzle, J. (2007). Conservation agriculture as practiced in Kenya: Two case studies. Nairobi: African Conservation Tillage Network and Food and Agriculture Organization of the United Nations.

Nyanga, P.H. 2012. Factors influencing adoption and area under conservation agriculture: A mixed methods approach. Sust. Agric. Res. 1, 1-14.

Vishwakarma, A.K ., Wanjari, R.H., Brajendra and Gopal, R. (2017). Weed management in conservation agriculture: A brief review. J. Pharmcol. Phytoch.. SP1, 502-506.

Yakadri, M., Rani, P.L., Prakash, T.R., Madhavi, M. and Mahesh, N. (2015). Weed management in zero till-maize. Indian J. Weed Sci. 47, 240–245.

Suggested reading material

Hossain, A., Islam, T., Nurislam, Ahmed, S., Sarkar, K. and Gathala, M.K. (2019). Chemical weed management in maize (Zea mays L.) under conservation agricultural systems: an outlook of the Eastern Gangetic Plains in South-Asia. In book: Maize - Production and Uses. Publisher: Intech Open, UK.

Lee, N. and Thierfelder, C. (2017). Weed control under conservation agriculture in dryland smallholder farming systems of southern Africa. A review. Agron. Sustain. Dev. 37: 24-48.

Nichols, V., Verhulst, N., Cox, R. and Govaerts, B. (2015). Weed dynamics and conservation agriculture principles: A review. Field Crops Res. 183, 56–68

Rahman, M.M. (2017) Weed Management in conservation agriculture. Adv. Plants Agric. Res. 7: 00253. DOI: 10.15406/apar.2017.07.00257

Ramesh, K. (2015). Weed problems, ecology, and management options in conservation agriculture: issues and perspectives. Adv. Agron. 131, 251-303.

Sustainet, E.A. (2010). Technical Manual for farmers and Field Extension Service Providers: Conservation Agriculture. Sustainable Agriculture Information Initiative, Nairobi.

Sims, B., Corsi, S., Gbehounou, G., Kienzle, J., Taguchi, M. and Friedrich, T. (2018). Sustainable weed management for conservation agriculture: Options for smallholder farmers. Agriculture 8(8):118. DOI: " 10.3390/agriculture8080118

4.5 Integrated Pest Management in Conservation Agriculture

The intensification of agricultural practices has provided opportunities for a number of pests and diseases to thrive in a range of crops. Insect pests and plant diseases affect crop yields, so it is essential to effectively control the insects and pests. Crop losses due to insect pests in Indian agriculture are assessed as more than 20%. Cultivation techniques interact with different pest species in different ways and can result in greater or lesser antagonistic pressure dependent upon the organism concerned. CA increases biodiversity of both flora and fauna which helps to control insect pests. In CA, residue mulch and cover crops that are present on the soil surface provide habitats for numerous insects and bacteria and fungi. Thus, more insects and microorganisms may occur as they are able to hibernate until the next crop. At the same time the soil cover provides habitats for natural enemies of pests and diseases occurring in crops, but at the same time beneficial organisms can act as parasites on eggs of certain species. Thus, new balances between the species created under CA is determined by the quantity of residue left on the surface and the crop rotation practiced. Presently, limited information is available on the effects of CA on pest dynamics and control in different crops. Greater insect pest problems in CA systems is not a limiting factor. CA changes the physical, chemical and biological properties of soil, which can also inhibit or enhance useful and harmful fauna. System specific pest management is sometimes needed and there is a need for awareness of potential problems.

Pest and disease management includes cultural, mechanical, biological and chemical methods. It is necessary to integrate cultural, biological, mechanical, and appropriate chemical and biotechnological control methods for pest management. Integrated Pest management (IPM) is defined as a pest management system that utilizes suitable techniques and methods against the pests in as compatible manner with the environment as possible with minimal risk to human health and thus, maintaining the pest population levels below those causing economic injury. justified and reduce or minimize risks to human health and the environment. The adverse effects of the injudicious use of chemical pesticides with extensive applications is that they result in high residue on the crop. IPM is a safer and environment friendly technology for pest and disease management. It is a set of strategies based on monitoring economic thresholds, monitoring and identifying pests and preventive measures to determine if and when pest treatment is best applied. The objectives of IPM are: 1. Reduced crop loss and maximizing crop production, 2. Minimize environmental pollution, 3. Reduced chemical contamination of food and the environment, 4. Maintain ecological balance with minimum disturbance to ecosystem and 5. Reducing pesticide use and management cost. In practicing IPM, a four-step approach is used: (1) setting action thresholds, (2) monitoring and identifying pests, (3) prevention, and (4) control (insect pests, rodents and diseases, etc.

Insect Pests and Disease Infestation in CA

The organic mulch cover and diversified crop rotations allow for increased biodiversity above ground including that of predators and parasitoids, resulting in improved pest control, better crop health and an estimated 20% reduction of pesticide use in the long term. Crop residues as mulch in CA have indirect effects on pests through lowering soil temperature and increasing soil moisture content. Crop residues directly affect egg laying of beetles and cutworms, and survival of a number of insects, both harmful and beneficial. Crop residues on the soil surface may favour snails and slugs, causing damage to crops. Crop residues generally increase diversity of useful arthropods and help in reducing pest pressure. Further, the decomposition of crop residues brings out a chemical change by producing phytotoxic substances in soil which may affect the host reaction to pests.

Among several factors, mulching and tillage practices in CA can affect the severity of plant disease. CA also affects the level of nutrients available for both plant and pathogen which affects disease severity. There are conflicting reports on insect-pest dynamics under CA. While reduced tillage generally increases the number of insect pests and increases the diversity of predators and parasites of crop-damaging insects, crop rotations used in CA can reduce the insect pest population by breaking the cycles of insect pests, diseases, and weeds. Increased pest and weed problems during the 'transition period' are major hurdles in adoption of CA by farmers. Population of termite and white grubs generally increases under the ZT. However, the effect of crop residues on termite damage is contentious. Under sufficient crop residues, white grubs do not damage the crop even at a very high density. However, at some of the sites, organic mulching has been reported to increase damage of cutworms due to moisture conservation.

Some scientists argue that reduced tillage and soil cover can protect the biological components of the soil and keep pests and diseases under control while increasing biological diversity. Moreover, CA practices which enhance biological activity and diversity and predators/ competitors can improve pest management. Crop rotation is important under ZT as it decreases pathogen numbers and reduces pathogen carryover from one season to another. Zero tillage over the long term creates favorable conditions for the development of predators, by creating a new ecological stability. Crop residues are sources of food for bacteria, fungi, nematodes, earthworms, and arthropods which can cause major changes in disease pressure in CA. Better disease control has been reported in ZT and conservation tillage compared with CT (Govaerts et al. 2007a). Ground cover promotes above- and belowground biological diversity and there are more beneficial insects in fields with ground cover and mulch. Thus, CA not only favors insect biodiversity conservation but also has a positive impact on birds, small mammals, reptiles, and earthworms. Biodiversity provides resistant genes, anti-insect compounds, natural enemies (NEs: predators, parasitoids, entomopathogens) of pests, and community ecology-level effects to check pest attacks in the field. Biodiversity does not function well under the common practices of conventional agriculture.

CA systems are at greater risk to a few insect pests (e.g. cutworms, aphids, false chinch bug, grasshoppers, slugs), but these tend to be occasional or minor pests. Impact on other, more important pests is generally small. CA has sporadic but mostly positive impacts on populations of beneficial arthropods dependent upon the use of cover crops, etc. Studies show that aphid infestations and aphid populations were always lower in CA systems compared to conventional till systems. Snails increase in CA systems but are little economic importance. Increases in pink stem borer (PSB, *Sesamia inferens* Walker) damage in wheat under CA has been noticed at few places in rice-wheat system in NW India. However, the damage was below 1%. The PSB generally attacks the wheat crop at seedling stage. The larva bore into the stem of young plant and kills the central shoot causing 'dead heart'. The infested tillers first look pale brown and ultimately dry up. At the ear emergence due to its attack 'white ears' are produced which have little or chaffy grains. Spray the crop with quinalphos 25 EC @ 400 ml/acre. Removal or destruction of the stubbles at the time of first ploughing after harvest of rice reduces the carry over to wheat. Ploughing and flooding field is also effective in killing the larvae.

The larvae of armyworm (*Mythimna separate Wlk.)* hide during the day under thick residue mulch but feed during night or early morning. The larvae are shy remain hidden in tillers, feed at night in the shade or at dawn and dusk. The pest is destructive in the larval stage only. The rice-wheat cropping in north western plains of India encourages build-up of armyworm and pink stem borer. Its attack can be located from the presence of larvae and blackish green faecal pallets on the ground close to the stem of the plant. At higher populations it defoliates the plants completely and feed on the grains in the milky stages. Under such situations it can cause yield losses up to 40%t. Nitrogen fertilizer should be used with care as the improved nutrition causes greater armyworm fecundity and more larval feeding and survival. Flooding limits plant to plant dispersal of larvae. The grown-up larvae feed on leaves, flag leaf, awns, glumes and on the developing grains. To control this pest, spray the crop with dichlorvos 85 SL@ 200ml/acre or qinalphos 25 EC @400ml /acre in 80-100 litres of water with a knapsack sprayer. To obtain better control always spray the crop in the evening hours because larvae are more active at this time.

Termites (*Microtermes obesi* Holmgren and *Odontotermes obesus* Rambur) in CA fields is again debatable. Few reports point out increased infestation of termites in CA fields than conventional fields, while other studies report lesser crop damage due to termite attack in CA. At the ear head stage of wheat when the roots of attacked plant are completely or partially eaten, such plants dry up without producing any grains (white ears) and can be easily pulled out. For termite control under CA, it is recommended to use a higher seed rate to compensate for yield losses to termites. Seed treatment is recommended with fipronil 5% SC @ 6 ml or chlorpyriphos 20EC @4ml per kg seed. Seed treatment is the most effective and economical method of termite control as compared to broadcasting of treated sand. Seed treated with chlorpyriphos 20 EC @ 300ml per 80 kg seed is also less attacked by birds.

Strategies for pest Management

The contradictory reports incite concerns regarding reduced yields and increased insect pest problems under CA. It is therefore necessary to integrate alternative cultural, biological, mechanical, and appropriate chemical and biotechnological control methods for pest management. IPM is not only compatible with CA but also works on similar principles. For example, IPM enhances biological processes and expands its practices from both crop and pest management to the whole process of crop production. The augmentation of soil microbiota would not be possible without adopting IPM practices. Similarly, CA depends on enhanced biological activity in the field to control insect pests and other disease-causing soil biota. IPM promotes the judicious use of crop rotations. and other beneficial plant associations as well as agrochemicals to control insect pests and disease problems. With the passage of time, enhanced biological activity brought on by CA technologies and IPM, results in less agrochemical use for crop protection. CA does not specify recommendations for pest control, so would benefit if combined with IPM which uses information on the life cycles of pests and their interaction with the environment. Thus, CA and IPM are economical and pose the least possible risk to human health, property, and the environment.

Non-judicious application of pesticides may disrupt the ecosystem and cause pest outbreaks. Therefore, integrated pest management (IPM) should be adopted as a necessary component of a CA system. Both IPM and CA work on the same principles to help increase biodiversity and conservation of natural resources. Sustainable pest management for crop production is possible in CA management systems by using IPM in combination with biotechnology and precision agriculture (PA). IPM, also known as integrated pest control (IPC), which integrates different practice cultural, biological, mechanical, and appropriate chemical control methods for economic control of pests to suppress pest populations below the economic injury level is needed. An integrated strategy for the management of major pests and diseases is possible by (i) breeding new varieties with built-in resistance, (ii) evolving efficient methods of pest control through pest surveys and monitoring, and (iii) biological control of pests with the help of conservation and augmentation of natural enemies like parasites, predators and insect pathogens. Strategies to improve adoption of IPM include: (i). Draw up spray application programs according to crop growth and production patterns, (ii). Follow pesticide label recommendations. Monitor the pest infestation behavior to see if it persists or declines as a result of the spray application, (iii). Training of the farmers and extension personnel in IPM methodology, (iv). Aggressive demonstration campaigns by R&D institutions in collaboration with state functionaries and non-governmental organizations (NGOs) (v). Improved availability of critical inputs biopesticides, bioagents and resistant varieties, (vi). Development of monitoring tools and forewarning systems, (vii). Advocate use of safer pesticides and appropriate application methods, viii). Research on multiple disease and pest resistant varieties, and (ix). Holistic integration of all information to develop bio-intensive and cost-effective practices. Economically viable IPM strategies have been developed for the control of major pests in rice, cotton, pulses, sugarcane, etc.

Cultural and Physical Pest Control

It includes crop production practices that make crop environment less susceptible to pests. Crop rotation/intercropping and residue mulch as in CA, manipulation of planting and harvesting dates, manipulation of plant and row spacing, balanced fertilizer use, efficient irrigation, trap cropping, and destruction of old crop debris are a few examples of cultural methods that are used to manage the pests. Cultural and physical controls are selected based on knowledge of pest biology and development. For example, shaking of the pigeonpea plant is a common practice to remove *Helicoverpa* larvae. Traps and sticky insect traps can be used to control pests.

Biological Control

These include augmentation and conservation of natural enemies of pests such as insect predators, parasitoids, parasitic nematodes, fungi and bacteria. In IPM programme, native natural enemy populations are conserved, and non-native agents may be released with utmost caution. *Trichogramma* species are the most popular parasitoids being applied on a number of host crops. Other microorganisms such as *Verticillium* spp., *Aspergillus* spp., *Bacillus* spp. and *Pseudomonas* spp. that attack and suppress the plant pathogens have also been exploited as biological control agents. Other biological control methods are; beneficial insects, parasites, predators, sex attractants, irradiation of males, Selective Breeding, and release or augment microbial pesticides. Pheromone traps have got advantage over other monitoring tools such as light and sticky traps. Control of mealy bug and lepidopterous pests affecting cotton, etc. are a few examples where success has been achieved through the release of biocontrol agents.

Chemical Control

Pesticides are used to keep the pest populations below economically damaging levels when the pests cannot be controlled by other means. The pesticides selected should be specific for the target pest and disease and should have the least side effects on human health, non-target organisms, and the environment. Pesticides include both the synthetic pesticides and plant-derived pesticides. Synthetic pesticides include a wide range of man-made chemicals. These are easy to use, fast-acting and relatively inexpensive. Ideally, pesticides should be used as a last resort in IPM programmes because of their potential negative effect on the environment.

The persistent use of the same chemical class of pesticides will result in pest resistance to the pesticides. The incorrect applications can upset the ecological balance of pests on the farm, the introduction of new pests and diseases, increased pest resistance to pesticides, and the destruction of beneficial insects such as bees and predators. Synthetic chemical pesticides should only be applied as a last resort when there are no adequate biological, cultural, or non-synthetic chemical alternatives available, and the use of pesticides is economically justified.

Biotechnological Approaches

Biotechnology and genetic engineering help to generate crop plants with improved resistance against insect pests, pathogenic bacteria, and fungi. Biotechnological and genetic engineering approaches will help support plant health, stabilize yield, and increase food safety along with other strategies of crop production. Microbial peptides from the bacterium *Bacillus thuringiensis* (*Bt*) have strong insecticidal potential against certain insects. Insecticidal properties of plant lectins are useful tools that can contribute to the development of IPM strategies with minimal effect(s) on nontarget organisms. Insect-resistant transgenic crops that express *Bt* toxins technology have been deployed commercially to protect crops against lepidopteran and coleopteran pests, excluding many other important pest species as dipteran pests like flies. Suppression of the expression of specific gene(s) in the pest by the Ribonucleic acid interference (RNAi) technique, offers the possibility of effective protection against any species, since genes necessary for survival, growth, development, reproduction, or feeding success can be targeted. Another biotechnological approach for pest management is the sterile insect technique (SIT). Although SIT has been successfully applied for some species, each step—like mass rearing, sex separation for only-male releases, sterilization and marking for monitoring—can be improved biotechnologically to optimize efficiency and reduce costs of ongoing programs or to transfer this effective technique to a wider range of species. Genetic-control-based SIT uses the release of mass-reared, sterile insects to cause infertile mating that reduce the level of the pest population. SIT is considered an environment friendly alternative to insecticides for insect species that can be mass reared in artificial settings. The biotechnological approaches (insect peptides, RNAi, SIT) will be effective tools for managing the insect pest population in the future.

Conclusion and Future Perspectives

The objectives of IPM and CA are the same: sustain productivity, conserve natural resources, reduce production costs, improve environmental health, maintain biodiversity, and reduce agrochemical use for crop production/protection. The use of pesticides still dominates the management of insect pests and is a health hazard for humans and the environment.
IPM requires knowledge of crop-susceptible stages and the nature of insect pests, as well as increased monitoring. Increased diversity of microorganisms, and insects under CA will be effective at keeping the insect pest population at acceptable level. Biotechnological approaches will be effective tools for managing the insect pest population in the future. In future, the focus will be on CA systems which provide high-quality food with low risks to the environment and public health. There is no evidence of complete control of insect pests in CA farming systems, which remains a challenge for researchers, farmers, and agriculture policy makers. The best option in this regard is IPM by integrating different techniques to keep insect pest populations at acceptable levels in CA cropping systems.

Suggested reading material

Leake, A.R. (2015). Integrated pest management for conservation agriculture. 271-279. In: *Conservation Agriculture* (M. Farooq, K. H. M. Siddique, eds.). © Springer International Publishing Switzerland.

Nawaz, A. and Ahmad, J.A. (2015). Insect pest management in conservation agriculture. 133-155. In: *Conservation Agriculture* (M. Farooq, K. H. M. Siddique, eds.) © Springer International Publishing Switzerland.

Singh, J.K., Yadav, K.K. and Kunar, V. (2017). Integrated pest management: conservation practices for agriculture and environment. Inter. J. Environ. Rehabil. Cons. 8, 17 – 28.

5 Conservation Agriculture for Sustainable Soil Health

The intensification of agriculture in many of productive regions of the world has resulted in degradation of soil health characterized by low organic matter, poor physical and biological properties, poor nutrient cycling, increasing pathogens load and nutrient deficiencies threatening agricultural production system. The restoration of soil health for sustainable crop production is a major concern in developing countries. We need to increase understanding of the importance of soil health for food security, climate change adaptation and mitigation, and essential ecosystem functions. Worldwide, an estimated 2 billion hectares of land are considered degraded, that is, less productive due to deterioration of essential soil processes. Asia, Africa, and Latin America together account for an estimated 75% of the global area of degraded land, with 750, 490 and 240 million hectares, respectively. To meet the increasing demand for food for the rising population in developing countries, there is strong need for producing more and more food. The CA practices have been widely promoted to arrest soil health degradation, increase crop yields and reduce environmental footprints, and making agricultural systems more resilient to climate change. It may take about3-5 years of continuous CA to get positive effects on health.

Causes of soil health degradation due to CT include:

- Tillage induced soil organic matter decline,
- Soil structural degradation,
- Water and wind erosion,
- Reduced water infiltration rates,
- Surface sealing and crusting, soil compaction,
- Insufficient or non-return of organic materials, removal/burning of crop residues,
- Excessive use of agricultural inputs: chemical fertilizers, herbicides, pesticides

Soil Health Defined

Soil health is defined as the capacity of a soil to function and sustain plant and animal productivity, maintain or enhance water and air quality and promote plant and animal health. According to Kibblewhite *et al.* (2008), a healthy soil is one that is capable of supporting the production of food and fibre to a level, and with a quality, sufficient to meet human requirements, and to continue to sustain those functions that are essential to maintain the quality of life for humans and the conservation of biodiversity with respect to both present and future needs. Soil health is governed by a number of physical, chemical and biological attributes and processes. ‘Soil health’, is invariably interchanged with the term ‘soil quality’. Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots (e.g., nitrogen-fixing bacteria and mycorrhizal fungi); recycle essential plant nutrients; improve soil structure (e.g., aggregate stability) with positive consequences for soil water and nutrient holding capacity, and ultimately improve crop production.

Characteristics of a Healthy Soil

- Sufficient depth
- Sufficient supply of plant nutrients
- Low population of plant pathogens and insect pests
- Accept, hold and release water to plants
- Good soil drainage
- Promote and sustain root growth.
- Large population of beneficial organisms
- Low weed pressure
- Free of chemicals & toxins that may harm the crop

- Resistant to degradation due to erosion
- Produce healthy crops over the long-term without increasing levels of inputs
- Resilience to weather extremes.

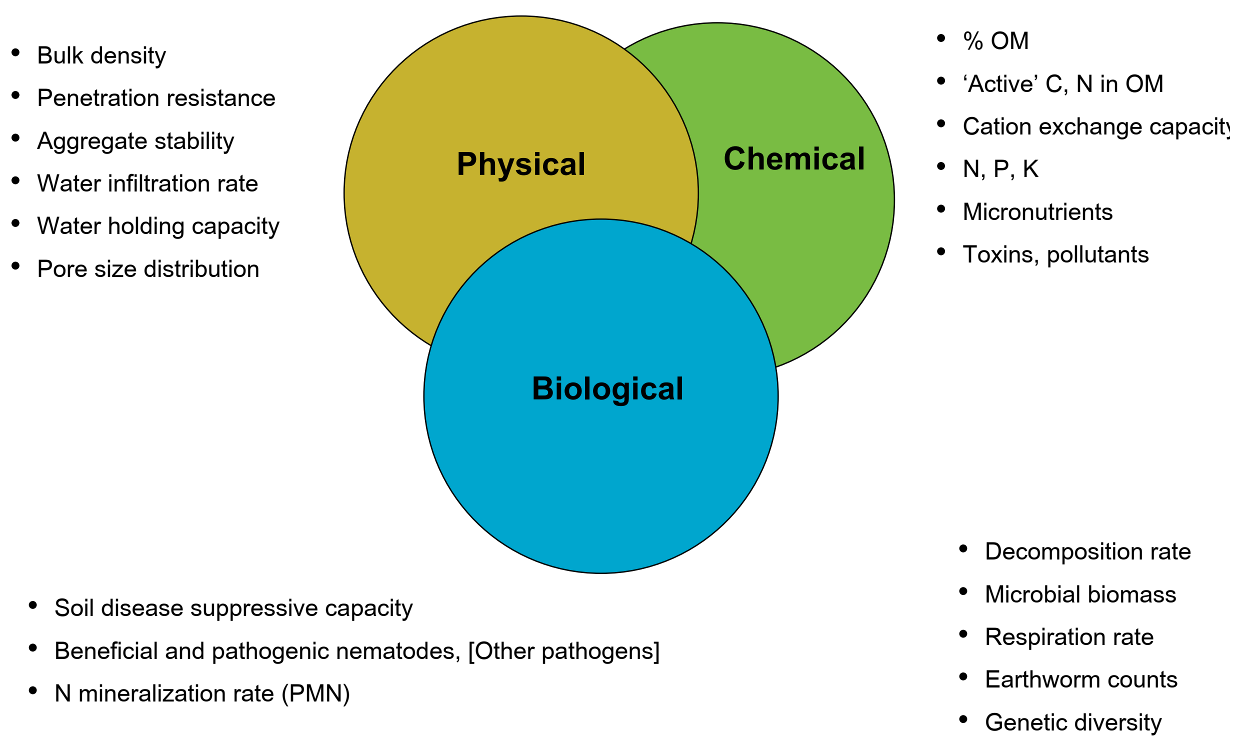
Significance of Soil Health

'Soil health', has in recent years, become associated with sustainability in agriculture. Healthy soils are highly productive, reduce production costs and improve profits. Besides these direct effects, healthy soils hold more water and loses less water through runoff and evaporation thereby acts as the buffer in climate-sensitive situation. Most of the biological, chemical and physical properties, which are attributable to improved soil health come from the maintenance or improvement of soil organic matter. In 2015, Food and Agriculture Organisation (FAO) gave slogan of 'Healthy soils for healthy life' and laid emphasis on sustainable management of soils which can be possible only by knowing health of soil (http://www.fao.org/soils-portal/en/). Building and maintaining soil health will be critical to meet the increasing food needs and safe and nutritious food for future populations. We know that soil, plant, human and animal health are interrelated.

Soil Health Assessment

The soil health monitoring is based on estimation of soil condition using a set of independent indicators of specific soil properties—physical, chemical and biological and these indicators in turn are affected by the CA practices. Any comprehensive soil health assessment consists of physical, chemical, and biological components (Fig. 5.1). Soil health assessment can be greatly improved by expanding measurements for the soil biological diversity and microbial components to be included as critical indicators of soil biological processes. Although many indicators and indices of soil health have been proposed, a globally acceptable and applicable methodology of assessment of soil health is still not in place. Key indicators of soil health are: physical (bulk density; water aggregate stability; mean weighted diameter; infiltration rate; water filled pore space;), chemical (pH, electrical conductivity, available P, K and micronutrients; cation exchange capacity, total N, potentially mineralizable N) and biological (key organisms and community structure; e.g. earthworms, metabolic quotient and phenotypic profiling , enzyme activity; basal soil respiration, microrhizae). Recent rapid developments in soil biology have prompted the feasibility of indicators based on genotypic

Figure 5.1. Soil health indicators



and phenotypic community diversity. Molecular methods focusing on DNA and RNA hold great potential to perform faster, cheaper and more informative measurements of soil biota and soil processes than conventional methods. Pools of soil organic matter such as labile or active carbon are typically more sensitive to disturbance than total soil organic matter and can give a better indication about soil processes. The measurement of labile pools includes: particulate organic matter, permanganate-oxidizable carbon (active C), water-soluble carbon, also called dissolved organic carbon and C content in microaggregate-within-macroaggregate fraction. The soil health indicators should correlate well with ecosystem processes, integrate soil properties and processes, be user-friendly and be sensitive to management and climate.

Impact of CA on Soil Health Improvement

CA can enhance soil properties crucial for sustainable soil management. There are examples from around the world where properly implemented CA systems have substantially improved soil health (physical, chemical and biological indicators) and agronomic yields. Long-term trials showed that CA practices do improve soil organic matter and related soil biological, chemical and physical properties. The main perceived benefits driving the adoption of CA practices are improved water and soil conservation, consequent on improved soil protection from the retained crop residues as well as reduced costs in terms of fuel. Positive effects on soil physical quality (structure and water infiltration rate) are especially relevant to erosion control in erosive climate and erodible soils of the India and West Africa.

The improvement in physical properties with CA based practices include improved soil structure, increase in hydraulic conductivity and reduction in bulk density of soil by modifying soil structure and aggregate stability. In CA, soils with a greater content of organic matter and greater natural fertility, are more and better prepared to respond to adverse climatic conditions that contribute to their degradation. Mulching with plant residues raises the minimum soil temperature in winter due to reduction in upward heat flux from soil and decreases soil temperature during summer due to shading effect. In CA, sufficiently porous surface permits easy entry by rainfall or irrigation water. Retention of crop residues on the soil surface slows the runoff by acting as tiny dams, reduces surface crust formation and enhances infiltration. The channels (macro pores) created by earthworms and old plant roots, when left intact with ZT, improve infiltration to help reduce or eliminate runoff. Reduced evaporation from the upper strata of soil coupled with improved soil characteristics essentially leads to higher crop yield in many cropping and climatic situations. In the areas where irrigation is not possible and agriculture is totally dependent on rain rainwater there mulching in CA conserves the soil moisture and has significant impact on crop growth.

The crop residues act as a reservoir for plant nutrients, increase cation exchange capacity (CEC), provide congenial environment for biological N_2 fixation, increase microbial biomass and enhance activities of enzymes such as dehydrogenase and alkaline phosphatase. Increased microbial biomass can enhance nutrient availability in soil as well as act as sink and source of plant nutrients. Leaving substantial amounts of crop residues evenly distributed over the soil surface reduces wind and water erosions, increases water infiltration and moisture retention, and reduces surface sediment and water runoff. The crop residues also play an important role in amelioration of soil acidity through the release of hydroxyls during the decomposition of residues with higher C:N, and soil alkalinity through release of carboxyls. The role of crop residues on carbon sequestration in soils would be an added advantage in relation to climate change and GHGs mitigation. While ZT and soil organic C build-up contribute to stable soil structure, this undisturbed structure produces macro pores and preferential flow channels that can direct nutrients downward into deeper parts of the soil profile. CA builds a stratified layer of crop nutrients, especially P on or near the soil surface. Healthy Soil accommodates active and diverse populations of beneficial organisms, with minimal plant pest populations. Other important aspect of soil health is the soil's ability to supply nutrients to the crop, and then using the right sources of nutrients to make up for any shortcomings in what the soil can provide. In CA, crop residues provide food for microbial population. The increase in SOM help for retaining both water and readily leachable nutrients. CA practices are a successful operation with good soil health and crop production. It had taken the farmer many years to get healthy soils. In CA, earthworm population will increase and help in decomposition of the residues and improving soil health.

CA has become a necessity in view of widespread problems of resource degradation, which accompanied the past strategies to enhance production with little concern for soil degradation. CA systems that enhance soil health also improve and sustain productivity. Establishment and maintenance of soil health is inextricably linked to the achievement of effective and efficient nutrient management goal in CA. The constructive changes in soil properties following conservation tillage and crop residue retention led to increased crop productivity over conventional CT.

5.1 Effect on Soil Physical Properties

Conventional agricultural practices lead to soil erosion and carbon loss thereby deterioration of soil physical health degradation. This structural degradation of the soil results in the formation of crusts and compactions which not only leads to soil erosion but also adversely affects the crop performance. The physical properties of the soil include colour, texture, structure, porosity, density, consistency, temperature, and air. Soil physical quality is considered to be poor when soil exhibits one or more of the following symptoms viz. poor water retention, infiltration, aeration, root growth and workability, and hard-setting and runoff. CA improves soil physical (e.g., structure, infiltration rate, plant available water capacity) quality. Information from the literature suggests that CA improves soil aggregation, lowers bulk density and soil penetration resistance, increases infiltration and soil moisture content, reduces soil erosion, runoff, crusting and moderates soil temperature) are generally more favorable with CA compared to tillage-based systems. The increase in soil organic carbon under CA has positive effect on soil physical, chemical, and biological properties which lead to improvement in the soil health. The impact of CA on soil physical properties (structure, porosity, bulk density, consistency, infiltration, temperature,) is discussed below.

Soil erosion: Excessive tillage as practiced in CT causes degradation of soils due to water and wing erosion, and compaction. Due to erosion during last 40 years, about 30 % of the world's arable land has become unproductive and most of it has been abandoned for agriculture. CA is considered as a suitable technique for control of soil erosion. CA maintains permanent soil covers which minimize the direct impact of the raindrops on the soil, increase the infiltration and reduce soil erosion. The ZT and maintenance of permanent soil covers in CA also plays an important role in reduction of wind erosion. CA leads to formation of stable soil aggregates and ultimately result in less soil erosion. Surface mulch in CA is important for intercepting rainfall energy, maintaining structural integrity, increasing infiltration rates and reducing runoff thereby increasing water storage in the soil. The soil loss with surface mulch can be reduced by up to 50%. Mean runoff and soil loss with CA plots were ~45 and ~54% less, respectively than conventional agriculture plots. Maximum runoff was recorded from plots where CA was not practiced (Table 5.1). CA treatment reduced runoff significantly compared

Table 5.1. Effect of conservation agriculture impact on crop productivity and conservation efficiency on a land with 2% slope at Dehradun, India

Particulars	Conventional agriculture	Conservation agriculture
Water loss (% of rain)	39.8	21.9
Soil loss (t ha^{-1} yr^{-1})	7.2	3.5
Grain yield of maize (kg ha^{-1})	1570	2000
Grain yield of wheat after maize (kg ha^{-1})	950	1700
Weed biomass for mulching (kg ha^{-1} yr^{-1})	-	2100
Moisture conservation for wheat (mm) compared to fallow	28.1	58.5

to conventional agriculture; probably due to the dense vegetation resulting in reduced runoff and silt deposition.

Soil structure and aggregation: Soil structure is often expressed as the degree of stability of aggregates. The stability of soil structure is the ability of aggregates to remain integral whilst exposed to diverse stresses. Aggregate stability and proportion of macro–aggregate strongly influence carbon sequestration, and often degradation of large aggregates induces SOC loss. Aggregation is a dynamic process that depends on various agents such as soil fauna, roots, inorganic binding agents and environmental variables. Soils under CA (ZT with residue retention) are more stable and less susceptible to structural deterioration, while conventionally tilled soils are prone to erosion. Physical disturbance of soil structure through tillage results in a breakdown of soil aggregates and exposes fragments of roots and fungal hyphae, which are major binding agents for macroaggregates. In rice-maize system, there were 35% and 47% higher for >2 mm size and 15.2% for 0.25–2.0 mm size water stable aggregates (WSAs) under ZT system compared to TPR/ CTM (puddled transplanted rice/ conventional till maize) ((Singh et al., 2016). Residue retention increased the WSA of >2 mm and 0.25–2.0 mm size by 23% and 10.1% over residue removal respectively. ZT with residue retention increased WSA as well as mean weight diameter (MWD) compared to CT and ZT-R in maize-wheat system (Govaerts *et al*.,2009). Generally soil microbial and biochemical environment of ZT soils is less oxidative than that under CT. Besides this, the release of polysaccharide compounds during the decomposition of crop residue acts as a cementing agent and has a crucial role in macro–aggregate formation (2010; Choudhury et al., 2014).

In CA, ZT along with residue retention improves soil structure compared to CT. Water stable aggregation (WSA) and mean weight diameter (MWD) are generally more in CA plots with ZT with soil surface residue retained. The increase of soil organic carbon and earthworm population under CA leads to improved soil aggregate stability over CT. CA produces significantly greater proportion of macro aggregates (>2 mm) compared with CT. This was because of minimum tillage in CA which reduces the mechanical destruction to soil aggregates. As compared to CT, CA coupled with DSR increased 50% water stable macro-aggregates and decreased 10.1% water stable micro- aggregates in surface soil.

Soil bulk density, resistance and porosity: Soil bulk density is an important indicator of the change of soil structure and water retention capacity under different tillage systems. The effect of tillage and residue management on soil bulk density and porosity is mostly confined to the topsoil. CA reduces the soil bulk density, particularly in surface layers, compared to conventional agriculture due to less traffic and surface retention of crop residues. It has been widely reported that the soil bulk density is higher in the surface layer of CA than CT, but lower below 30 cm. In contrast, there are reports of lower bulk density under CA compared to CT. The relatively higher bulk density in the CT indicates the development of a compacted “hard pan” beneath tillage depth, caused by the traffic associated with tillage.

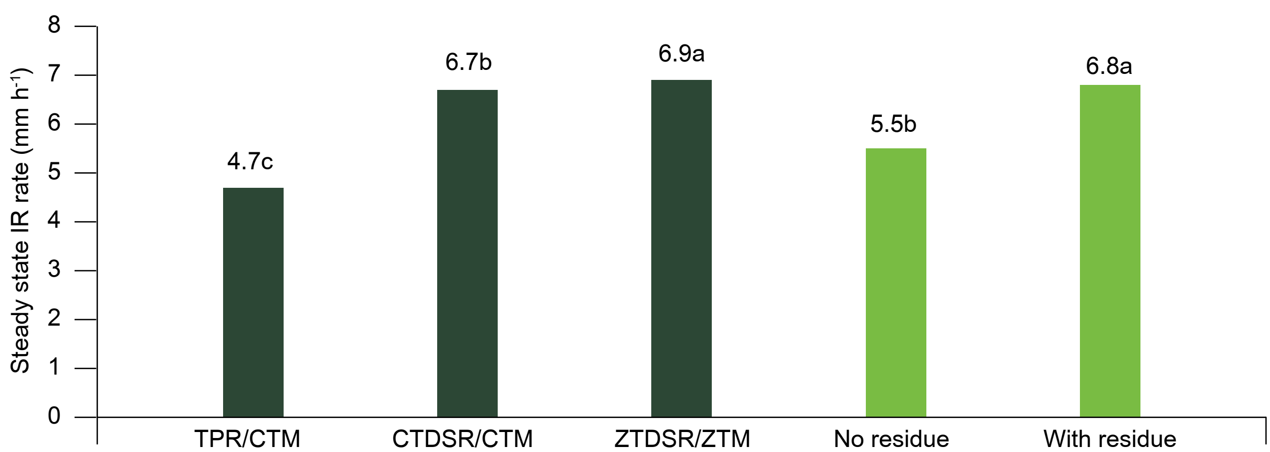
Puddling (wet tillage) in rice is known to increase soil bulk density immediately below the plough layer (15-30 cm) due to (i) destruction of soil aggregates, (ii) filling of macropores with finer soil particles, which ultimately reduces the porosity, and (iii) direct physical compaction caused by the tillage implements. Positive effect of crop residues on soil Db at the surface 10 cm depth has been reported by many researchers (Govaerts *et al*., 2009). Singh et al. (2016) recorded significantly lower soil bulk density in 0-15 cm and 15-30 cm layers in CA compared to CT plots after 5 years of rice-maize system. The decreased soil bulk density led to more soil aggregation and better root proliferation of roots and ultimately caused more water and nutrient uptake. The soil infiltration, storage and drainage of water, the gaseous changes, and the penetration ease by growing roots are determined by soil porosity. The pores are made by abiotic forces (tillage and traffic, freezing and thawing, drying and wetting) and by biotic factors (root growth, burrowing fauna). Numerous reports indicate that ZT along with surface residues under CA improves soil aggregation, decreases bulk density and ultimately penetration resistance to root growth reduces (Singh et al., 2016). Under CA, proper soil porosity is regained and maintained chiefly through biotic transformation of the organic matter fraction and soil-inhabiting fauna and flora - from micro-organisms such as bacteria to macro-organisms such as worms, termites and plants themselves.

***Soil crust*:** The formation of soil crust is not desirable for growth and productivity of the crop plants. The crust formation due to rain drop on surface is high in conventional tilled soils. Due to the formation of soil crust, aeration, soil water infiltration and its conductivity are decreases. This resulted in higher bulk density, decreased hydraulic conductivity, reduced air and water movement, negative heat fluxes, more soil erosion and hampered the seedling emergence. The retention of crop residues on the soil surface in CA plays important role in preventing the formation of soil crust. Further, the crop residue on soil surface abolishes the chances of formation soil crust even in the soils with low organic matter content and high silt percentage.

***Hydraulic conductivity and water-holding capacity*:** The hydraulic conductivity of a soil is a measure of the soil's ability to transmit water when submitted to a hydraulic gradient, simply the ease with which water can move in the soil. The hydraulic conductivity of soil (saturated and unsaturated) improved under ZT owing to either continuity of pores or flow of water through very few large pores. Residue retention and ZT under CA generally increases hydraulic conductivity due to the increase in number of macropores and pore diameter, and improvement in pore continuity. The increase soil organic matter content under CA will increase the water-holding capacity of the soil. The improved soil water storage increases WP under CA.

***Infiltration and runoff*:** Infiltration is the entry of water in the soil surface, higher the infiltration better will be water storage in the soil and lesser will be the run off losses (Fig. 5.2). Normally, infiltration rate is higher in CA compared to CT. The crop residues on soil surface prevents breakdown of soil macro-aggregates by preventing from the impact of cultural practices and rain drops. and check the formation of surface seals or crusts thereby improving infiltration rate. In fact, under CA increase in the activity of the earthworms and leaving the root channels undisturbed in turn leads to the presence of numerous macro-pores and voids resulting in higher rate of infiltration in the soil. The higher infiltration rate (cumulative and steady state) in CA plots compared to CT may be beneficial in the storage of rainwater and reducing runoff. The residues present in the surface act as a succession of barriers, reducing the runoff velocity and giving more time for infiltration. The lower infiltration rate in conventional till plots leads to yellowing of crop (wheat) after flood irrigation as well as when there is a heavy early in the season, particularly on fine-textured soils. The increase in rate of infiltration in permanent beds has been reported to range from 50-100% compared with conventional till systems. There reports showing an increase of 3.7 times under long-term (24 yrs) CA over conventional till with residue burn. The lower infiltration in conventional till as compared to ZT is due to breakdown of aggregates and formation of surface seal by the raindrop impact,

Figure 5.2. Effect of conservation agriculture practices on steady state infiltration (IR) 5 yrs after rice-maize system (Singh et al., 2016). TPR, puddled transplanted rice; M, maize; CT-conventional till, ZT, zero till; DSR, direct seeded rice.



increased compaction and reduction in pore proportion of the surface soil. In comparison to conventional till plot pores in no till are well connected and protected by the residue cover against raindrop impact and other physical intercultural operations.

***Soil water storage*:** Combined use of residue and ZT practices in CA increases storage of precipitation in the soil. Water storage in the soil profile up to one-meter depth was generally higher in CA plots during wheat growing season. The higher soil water content in CA plots than CT indicated the residue mulch reduced water evaporation during crop growing season (Yadvinder Singh and Sidhu, 2014). The increase in soil organic matter in CA plots may prove beneficial due to decrease in water holding capacity of soil. Another major advantage of CA, especially in the years of low rainfall, is the reduction in evaporation. Mulching in wheat in RW system has a significant positive effect on soil water conservation in CA systems and the effect was more pronounced in dry periods. The extra moisture in CA plots, achieved through increased infiltration and reduced evaporation, enables the production of an extra crop through relay planting, particularly in rainfed regions of India and West Africa.

***Soil temperature*:** Residue mulch provides 'buffering' against extreme temperatures at the soil surface which otherwise are capable of harming plant tissue at the soil/atmosphere interface, thus minimizing a potential cause of yields limitation. Higher soil temperatures in hot tropical regions and low soil temperature in temperate regions are the one of the major constraints to crop production. In tropical and sub-tropical countries, high soil temperatures adversely influence the seed germination, crop growth, soil microbial population. Organic cover in the form of crop residues, insulate the soil and captures a large amount of sunlight, causing less heat to flow into the soil and protecting the soil beneath from getting as warm as the bare soil during days. The ZT with residue mulch recorded 2 to 6 ^{o}C less soil maximum temperature in summer season as compared to the CT (Singh et al., 2016). Crop residue cover in CA buffers the soil temperature regime in surface layers by lowering (often between 2 and 8°C) maximum soil temperature and increasing (by 1-3°C) the minimum soil temperature compared to CT. The decreased soil temperatures in residue retained plot, especially at grain filling stage have positive effect on reducing canopy temperature and ultimately decreases the impact of terminal heat on the crop (Yadvinder-Singh et al., 2014). The residue retention in ZT acts as an insulator against the sharp decline in the soil temperature during night which resulted in less fluctuation in day and night temperature.

5.2. Effect on Soil Chemical Properties

Long-term intensive cropping systems appear to have deteriorated soil fertility in many regions, depleting major (e.g. N, P, K and S) and micro nutrients (e.g. Zn, Mn, Fe and Cu), and generating a nutrient imbalance. Important key indicators of soil chemical properties are provided in table 5.2. Soil chemical properties that are usually affected by tillage systems are soil organic carbon (SOC) content, pH, CEC, exchangeable cations, nitrogen, phosphorous, potash and other secondary and micro nutrients. Several of the analytical methods developed by the scientists which have been very useful in measuring the available nutrients status of soils, which is a component of soil health. These methods are being adopted extensively in the soil testing laboratories being functional at the district headquarters all over the country. Since the available nutrients status of soil would fluctuate depending on the crops grown and the nutrient management practices adopted, it is customary to do the soil testing once in 4 to 5 years under single cropped areas and once in 2 to 3 years in double cropped areas.

Effect of CA practices on nutrient dynamics in soils is also discussed in detail under chapter 4, section 4.2.1.

Conservation agriculture and soil organic carbon

In cultivated soils organic carbon (SOC) can progressively decrease, with a large part being removed annually (as crop residues) and much of it being lost by decomposition caused by CT. Since most of the agricultural soils of Africa and India are low in SOC, significant potential for C sequestration is expected. Potentially one-third of the carbon emitted in current fossil fuel use could

Table 5.2. Key chemical indicators of soil health

Selected indicator	Rationale
Organic carbon	Nutrient availability, indicator of physical and biological properties, and environmental quality
pH	Nutrient availability, chemical activity, pesticide absorption
Electrical conductivity	Defines crop growth, soil structure, water infiltration; presently lacking in most process models
Forms of N	Availability to crops, leaching potential, mineralization/immobilization rates, process modelling
Available N,P,K, and micronutrients	Capacity to support plant growth, environmental quality indicators
Total, N, P, K	Defines general improvement in soil fertility
Heavy metal pollutants and organic pollutants	Plant quality, and human and animal health

be offset by implementing CA globally in the next decade. SOC has a great influence on soil physical, chemical and biological properties, necessary for the development of its functions. Despite it being a relatively small component of soil in terms of volume, SOC is the single most important primary indicator of soil health as it exerts profound influence on the soil's chemical, physical, and biological properties. Organic matter improves the formation and stability of aggregates and considered as a source of energy for macro and meso fauna, and microorganisms of the soil.

Maintenance or improvement of SOC is a widely promoted benefit of CA systems. The reduction of erosion due to the implantation and development of CA, leads to an increase in the SOC content, which, in addition to being the basis of the C sink effect, improves physical and biological properties of soil, enhances the chemical and physical fertility of the soil, favours the development of the structure or aggregates, thus increasing soil resistance to erosion and favouring water infiltration. CA systems would help to mitigate GHG emissions contributing to global warming as a result of increase in SOC content. Practices that enhance soil organic matter are built into CA principles and include one or more of the following: minimal or ZT, mulching, diversifying cropping systems, using cover crops, crop residues as mulch and legume green manures/ nitrogen fixing crops. Many researchers from India have recorded significant increase in SOC content in CA plots compared to CT plots, particularly in 0-15 cm soil layer due to slower rates of organic matter oxidation and increased addition of C–input as crop residues after 2-5 yrs. ZT or reduced tillage in CA has ability to both reduce soil erosion and increase C sequestration in agricultural surface soils by increasing aggregate stability. CA has proven potential of converting many soils from sources to sinks of atmospheric C, sequestering carbon in soil as organic matter. Pacala and Socolow (2004) projected that globally conversion of all croplands to conservation tillage could sequester 25 Gt C over the next 50 years, marking it as one of the key global strategies for stabilizing atmospheric CO_2 concentrations. Potentially one-third of the C emitted in current fossil fuel use could be offset by implementing CA globally in the next decade. CA practices can generate C sequestration rates ranging from 0.9 to 3.5 t CO_2eq/ha per yr. Studies showed that CA can enhance soil carbon sequestration at a rate ranging from about 0.2 to 1.0 Mg/ha/year depending on the agro-ecological location and management practices (Corsi *et al.*, 2012). The increase in SOC by 1 Mg ha^{-1} yr^{-1} can increase food grain production by 32 million Mg yr^{-1} in developing countries. In a study from NW India, SOC was increased by 83% and 72% with CA based rice-wheat-mungbean and maize-wheat-mungbean system, respectively compared to conventional RW system (4.6 g kg^{-1}) (Jat et al., 2018). In another study, CA increased SOC content in both 0-15 and 15-30 cm layers and stock (0–30 cm depth) by 30% in comparison with CT maize-based cropping systems after 5 yrs (Table 5.3). In contrast to CA, conventional cultivation generally results in loss of soil C and N.

The benefits of CA practices in resource conservation, soil quality and farm profitability have been reported by many researchers (Ladha et al., 2009; Gathala et al., 2013). The lability–graded fractions of total organic carbon (TOC) provide valuable information related to the quality and persistence of soil organic carbon (Ghosh et al., 2012; Venkatesh et al., 2013). Very–labile C–fraction and labile C–fraction are highly prone to oxidation processes and therefore, higher concentrations of the these two fractions in CA based crop establishment treatments indicate that restricted oxidation of organic carbon in conservation tillage treatments (Nandan et al., 2019). Notably, higher passive C–pool in CA practices over conventional RW system suggests that conservation tillage could stabilize the recalcitrant form of carbon that persists longer in the soil.

Nanadan et al. (2019) observed strong relationship between TOC and grain yield of rice (r=0.63, p < 0.001), wheat (r=62), and maize (r=0.60) reflects the importance of SOC in sustaining the crop productivity of rice–based cropping system of the tropical IGP. The higher response of winter crops (wheat and maize) to crop residue retention and ZT (wheat only) might be associated with the higher conserved soil moisture, improvement in physical properties, and moisture dependent plant nutrient accessibility (Nandan et al., 2019; Laik et al., 2014; Nath et al., 2017; Gathala et al. 2011).

Blair et al. (1995) proposed carbon management index (CMI), a multiplicative function of carbon pool index (CPI) and lability index (LI) as an indicator of the rate of change of SOM in response to land management changes in soil.

Carbon pool index (CPI) = Total C of a given land use/Total C of the reference plot

Lability index (LI) = [Labile C content of a given land use/Non-labile C (CNL)content of a given land use] * [Labile C content of the reference plot/ Non-labile carbon content of the reference plot]

Carbon management index (CMI) = CPI * LI * 100

Labile C is a more sensitive indicator of the C dynamics of the system than total C.

Labile C (CL) = C oxidized by 333 mM KMn04 and non-labile C (CNL) = C not oxidized by KMn04.

Soil pH, electric conductivity and cation exchange capacity

The soil chemical properties of the surface layer are generally more favourable under the CA systems than under the CT soil. Effect of CA on soil pH are inconsistent. While some studies showed no significant effect of CA on pH and electrical conductivity (EC) of normal soils, other studies recorded significant decrease in soil pH in partially reclaimed sodic soil in RW system (Table 5.4). In CA, pH of surface soil decreases due to decrease in sodium (Na) concentration when the crop residue remained in the field compared to residue removal, which has a major influence on the availability of a number of plant nutrients. Many studies show that soil chemical quality parameters such as EC, organic C, N mineralization, Olsen P, NH_4Ac K and available micronutrient contents were significantly influenced by various tillage and residue treatments, and the effects were restricted to the 0–15 cm soil layer. Cation exchange capacity (CEC) indicates the capacity of a soil to hold exchangeable cations. CA enhances soil organic carbon content in the soil and high organic carbon mean high CEC in the soil.

Nutrient availability

Crop rotations and *in-situ* residue management play a key role in CA systems where they facilitate

Table 5.3. Effect of long-term tillage (ZT: Zero tillage; CT: Conventional tillage) on total Soil organic carbon (SOC, on equivalent mass basis) in the 0–15 and 15–30 cm layers in maize-based cropping systems (Parihar et al., 2018).

Treatment	Soil organic carbon (g kg^{-1})		Total soil organic C stock (t ha^{-1})	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm
CA	6.32a	5.23a	14.8a	13.4a
CT	4.73b	4.33b	11.2b	10.7b

Table 5.4. Soil pH, electric conductivity (EC); bulk density (BD) and soil organic carbon (SOC) as influenced by CA systems after the 3 crop cycles (Choudhary et al., 2018b).

Cropping system	Treatment	pH (1:2)	EC ((dS m^{-1})	BD (Mg m^{-3})	SOC stock (t ha^{-1})
Rice-wheat	CT	7.91a	0.52a	1.47a	6.8d
	CA	7.88a	0.52a	1.35cd	10.5a
Maize-wheat	CT	7.96a	0.41b	1.38bc	7.5c
	CA	7.91a	0.38b	1.34d	10.2a

CT- Conventional till; ZT- Zero till; Means followed by the same letters within each column not statistically different ($p \leq 0.05$)

Table 5.5. Effect of conservation agriculture (CA) practices on chemical soil properties (0-15 cm) after 4 yrs of rice-wheat-mungbean (RW-MB) and maize-wheat-mungbean (MW-MB) systems on partially reclaimed soil (Jat et al., 2018).

Treatment	SOC (g/kg)	Total N (%)	Available nutrients (kg/ha)		
			N	P	K
Conv. RW	4.5b	0.14b	117c	16b	183c
CA-RW-MB	7.5a	0.19a	156b	22a	236b
CA-MW-MB	7.7a	0.19a	197a	20a	318a
	pH	Av. Zn (mg/kg)	Av. Cu (mg/kg)	Av. Fe (mg/kg)	Av. Mn (mg/kg)
Conv. RW	8.06a	4.8	2.7a	132b	813c
CA-RW-MB	7.84ab	9.2	2.7a	136a	986a
CA-MW-MB	7.60b	7.2	2.6a	88c	873b

soil fertility replenishment. During the first few years of CA, N is availability in soil is generally low mainly due to net immobilization and there may be a need for application of N fertilizer which can speed up the mineralization process. However, in the 2-3 years following the adoption of CA, soil microorganisms will significantly increase the N mineralization due to nutrient recycling through crop residues leading to less need for fertilizers. The scientific reports suggest that total N are higher in soils in long term experiments under CA due to increased release of nutrients owing to microbial activity and nutrient recycling compared to CT. Crop rotations with leguminous crops have the potential to increase soil N availability through biological nitrogen fixation. Nutrient loss may be minimized due to reduced runoff and the appropriate use of deep-rooting cover crops that recycle nutrients leached from the top soil (FAO, 2001). This leads to the greater availability of both native and applied nutrients to crop plants which can have a significant effect on fertilizer efficiency.

N availability was 33% and 68% higher at 0–15 cm depth in CA-based RW-mungbean and maize-wheat-mungbean systems, respectively, than conventional RW system. DTPA extractable Zn and Mn were also significantly higher under CA-based cereal systems compared to conventional RW system (Table 5.5). CA improved soil chemical properties and nutrient availability and have potential to reduce external fertilizer inputs in long run.

The biggest problem in P availability is its fixation in the soil. In CA, reduced mixing of the fertilizer in the soils leading to lower P-fixation and increases P availability to the crop plants. Accumulation of P at the surface of continuous CA is commonly observed. Conventional tillage disrupts and impairs soil pore networks including those of mycorrhizal hyphae, an important component for P availability in some soils. CA promotes better soil microbial fauna and flora and from theses many of the beneficial microbes act as phosphate solublizer and enhance the availability of native soil P. The crop residues are rich source of K and their retention along with ZT in CA has increased K availability in soils in the soil surface where crop roots proliferate. CA can improve crop yields at low rates of K application and can decrease crop response to applied K

(Jat et al., 2018). It has been widely reported that exchangeable Ca, Mg, and K contents were significantly higher in the surface soil under ZT. It is apparent that CA practices (tillage, residue management and crop rotation) have a significant impact on availability and transformation of micro-nutrients in soils.

CA practices increased soil available nutrients mainly available–P (16%), followed by available–K (12%), DTPA–extractable Zn (11%), and available–S (6%) over residue removal treatment (Nandan et al., 2019). Therefore, CA practices could be recommended in tropical rice–based cropping systems for improving soil quality and production sustainability. The improved soil fertility under CA is mainly because of additional nutrient input through left over crop residue. The effect of crop residue on soil available nutrients are expected to be additive over time. Notably, increased SOC often associates with higher microbial activity that also directly influences availability of P and S in the soil. The hydrolysis of organic materials results in low molecular weight aliphatic acids, which compete for P sorption sites and increasing concentration of solution P. Cereal crop residues are known as the rich source of K and thus retention of crop residues increased K in the soil. The results further suggest that, in long–term, the dose of mineral fertilizers may be reduced in residue retention treatments.

5.3. CA and Biological Indicators of Soil Health

Soil biology means the soil microbes present in the soil like bacteria, fungi, nematodes, earthworms etc. The soil organisms are responsible for decomposition of organic materials applied to the soil. Soil microorganisms play many functions that are critical for vigorous plant growth including nutrient cycling; decomposition of organic substances leading to SOC and aggregate formation; protection from plant pathogens; and synthesis of plant growth-regulating compounds for root growth stimulation and vegetative production. Soil microorganisms (microbial structural and functional diversity) and their activity (soil respiration rate or some enzymatic activities) appear to be excellent indicators of soil health like, because they respond quickly to changes in the soil ecosystem. In some instances, changes in microbial populations or activity can precede detectable changes in soil physical and chemical properties, thereby providing an early sign of soil improvement or an early warning of soil degradation. Studies suggest that that soil heath indicators (microbial biomass carbon, basal soil respiration, microbial quotient, dehydrogenase activity, fluorescence diacetate activity) the most sensitive for predicting short-term changes in soil quality under different CA practices can be used to identify the most sustainable CA-based practices and are the most sensitive for predicting short-term changes in soil quality under different CA practices. Soil biological properties are interconnected with other soil physical and chemical properties; e.g. aeration, soil organic matter, pH affect the activity of many microorganisms in soils which in turn perform relevant activities in carbon and nutrients cycling. Soil organic matter is a key factor affecting biological activity in soils under CA. It is the carbon source for many organisms, including soil microbiota. Not only the amount, but also the type of organic compounds in the soil determines its biological activity; e.g., microbial activity is greatly increased by incorporating fresh organic residues (such as green manure or crop residues), which can be readily mineralized by microbes.

One of the important benefits of the adoption of CA practices for agricultural ecosystems is the improvement of microbial biodiversity in general, and population in the soil in particular. Soil biodiversity plays a key role in fertility, nutrient absorption by plants, biodegradation processes, the elimination of hazardous compounds and natural pest control. In other words, richer and more biologically diverse soils have greater capacity to respond to extreme phenomena such as the incidence of heavy precipitation, temperature increase or the geographical displacement of pests and diseases, among others resulting from climate change. Soil organisms can be grouped intgo three categories depending upon body size: the microbiota (<100 μm diameter), the mesobiota (100 μm to 2 mm diameter), and the macrobiota (>2 mm diameter). Within the soil biota, the most important groups of both destructive and resource organisms are the bacteria, fungi, nematodes, arthropods (such as mites and insects), earthworms (mostly beneficial), and weeds. Surface residues as mulch, moderate soil temperatures, reduce evaporation, and improve biological activity in CA. It is well established that CA significantly increases earthworm population in soil than under ploughed soil. Earthworms play a major role in the recycling of nutrients and formation of stable aggregates (>250 µm). They remove organic material from the soil and incorporate them as a stable aggregates due to organic mucilage and/stable organo-mineral complexes. In addition, earthworms reduce bulk density and increase water infiltration, with the consequent advantages related to the improvement of soil moisture content. CA also increases rhizosphere activities significantly. Rhizospheric microorganisms can significantly affect plant development through the production of growth regulators, by decreasing the incidence of plant diseases, and by increasing nutrient availability to plants. It is only comparatively recently that the importance of the soil biota in maintaining soil quality, plant health, and soil resilience (the ability to recover from natural or anthropogenic disturbance) has been recognized.

Commonly used biological indicators of soil health

Microbial population (bacteria, fungi, actinomycetes): Determined by MPN and plate count method in the laboratory.

i. Microbial diversity: Determined by functional groups, or describing genetic diversity. Microbial community fingerprinting (substrate utilization, Fatty acid and nucleic acid composition)

ii. Presence of pathogens: Measured by different pathology techniques, from cultures to DNA profiling as decomposition but that do not produce a harvestable product).

iii. Nematode population (Beneficial and Parasitic)

iv. Weed seed bank

v. Mycorrhizal fungi: Glomalin content (Glomalin is a glycoprotein produced abundantly on hyphae and spores of arbuscular mycorrhizal fungi in soil and in roots)

vi. Non-symbiotic N fixing bacteria

vii. Potentially mineralizable nitrogen (PMN): It is considered an important indicator of soil health. It is measured as increase in mineral N content under standard laboratory conditions. It is an estimate of the amount of N that is immobilized in organic forms and potentially could be decomposed by microorganisms into a plant available form. Compared with CT systems, CA systems had significantly higher PMN. Consistent with the use of PMN as a soil health indicator, CA practices benefiting PMN also benefit yield.

viii. Soil microbial biomass (SMB): SMB (C, N, P, S) has commonly been used to assess below-ground microbial activity and is a sink and source for plant nutrients. ZT with residue retention increase the SMB of soil. Increased SBM increased soil aggregate formation, increased nutrient cycling through slow release of organically stored nutrients, thus builds soil fertility. CA practices contribute to increasing microbial activity, which improves the stability of aggregates. SMB is a reflection of soil to store and recycle nutrients, such as C, N, P & S. A uniform and continuous supply of C from organic crop residues serves as the energy source for microorganisms.

ix. Soil respiration: It is measured as CO_2 evolution under controlled conditions in the laboratory conditions or in the field. It provides a measure of biological activity, but does not indicate how many or what kind of organisms are present. Basal respiration (BR) is expressed as qCO2 (µg CO_2/mg soil.

x. Earthworm population: Density of earthworms

xi. Soil enzymes: Soil enzyme assays generally provide a measure of the potential microbial activity. Most extensively studied enzymes as an indicator of soil health/quality are; dehydrogenase activity (represents over all microbial activity of soil), arylsulphatase (involved in S-cycling), invertase (soil pollution; degree of soil erosion), phosphatase and phytase (soil available P), β-glucosidase (involved in plant residue degradation, soil C pool), protease (organic N-cycle, protein degradation) and flourescein diacetate (total microbial activity)

The changes in tillage, residue, and rotation practices in CA stimulate soil fauna and flora, including both pests and beneficial organisms. The fungal biomass is generally increased and bacterial biomass is decreased under CA compared to CT systems. Mycorrhizae (VAM) were also more abundant in soil under CA indicating better nutrient (P, N, K) mobilization, water availability and protection from root pathogens with these symbiotic fungi. Three years after the adoption of CA practices, increases of 208, 263, 210 and 48% in soil microbial biomass C (MBC) and N, dehydrogenase activity (DHA) and alkaline phosphatase activity (APA) were reported, respectively in maize-wheat system whereas corresponding increases were 83, 81, 44 and 13%, respectively, in rice-wheat system as compared with conventional systems (Table 5.6a & 5.6b). CA based MW system recorded the highest microbial population viz. bacteria, fungi and actinomycetes. Soil MBC, APA and micro-arthropod population were identified as the key indicators and contributed significantly towards soil quality index. The higher microbial population is likely to be the result of improved food source availability supplied by residue amendment.

The CA benefits various groups of microorganisms (bacteria, fungi, protozoa, nematodes, etc.) and their number. Soil under CA systems may have 50% more microorganisms than the soil under CT. It should be noted that a direct consequence of the increase of microorganisms in the edaphic profile is the increase of the structural soil stability.

The SQI values (integration of physical, chemical and biological indicators) show significant positive relation with and crop yields. Microbial communities in soils can be characterized based on cellular composition of phospholipid fatty acids (PLFA). The total PLFA content is a measure of the viable microbial biomass present in soil. Identification of individual PLFAs ("biomarkers") allows classification of specific functional groups of microorganisms (bacteria, actinobacteria, fungi and protists). Description of these microbial PLFA groups combined with information from other soil health indicators provides a robust understanding of the soil health under CA practices.

Soil health and crop yields

The yield levels of CA systems are comparable with conventional intensive tillage systems, which mean that CA does not lead to yield penalties. In few cases the change from tillage-based farming to CA can result in modest yield penalties during the first few years for instance due to changes in soil nutrient balance and locking up of nitrogen due to increase in soil microbial activity or in weed infestation. The improved soil health allows better root and plant development and crop health, and leads in the longer term to incremental

Table 5.6a. Effect of cropping system, tillage and residue management on soil biological properties after 3 years (Choudhary et al., 2018a).

Treatment	MBC (ug g-1)	MBN (ug g-1)	DHA	Total microbial population		
				Bacteria (cfu x 104 g-1 soil)	Fungi (cfu x 102 g-1 soil)	Actinomycetes (cfu x 104 g-1 soil)
Rice-wheat system						
CT	646b	201b	180b	74.7b	45.3b	38.5b
CA	1182a	364a	260a	86.7a	64.3a	50.8a
Maize-wheat system						
CT	895b	244b	219b	81.6b	54.3b	45.8b
CA	1990a	729a	558a	96.2a	77.3a	71.0a

Where CT- Conventional till; CFU- Colony forming unit. Means of column followed by the same letter does not differ significantly at p=0.05.

Table 5.6b. Increase (%) in microbial population and enzyme activities under CA compared to conventional practice in rice-wheat and maize-wheat systems

Cropping system	Microbial population			Enzyme activities		
	Bacteria	Fungi	Actinomycetes	Dehydrogenase	Alkaline phosphatase	β-glucosidase
Rice-wheat	26	61	92	140	42	12
Maize-wheat	28	68	98	210	49	13

improvement in yields and factor productivities until a new equilibrium is established. Sometimes reduction in crop yields under CA are generally the result of management errors during the learning and adaptation phase of adoption, which requires changes in all aspects of crop and cropping system management, particularly in fertilizer, pest and weed management regimes. In situations, where the actual yield levels of tillage-based systems are low compared to the genetic and agroecological potential of the crops, the changeover to CA results in immediate yield increases, particularly in legume crops. This has been the case in most developing countries so far. With this kind of crop response CA fulfils the multiple requirements of sustainable intensification mentioned in the beginning, since it is a production system with a high output potential. In drier years, when crop residue retention can enhance water conservation in soils, ultimately producing better yields. However, yield reduction under CA is sometimes in wet years. Under manual CA systems in many African countries, marked improvements in crop yield have been reported under smallholder farmers CA practices. A study carried out on fields of farmers in semi-arid Zambia showed that CA produced on average an additional 1 900 kg ha^{-1} of maize grain compared to the conventional mouldboard plough tillage (GART, 2008). The most benefit accrued from early planting as CA permitted farmers to plant with the first effective rains. Timely weeding was the second most important management factor in smallholder farmers responsible for increased yield as excessive weed growth is widely recognised as one of the main constraints in smallholder crop. The remaining benefits from CF were obtained from improved fertility due to precision application of fertiliser, soil fertility increases from crop residue mulching and inclusion of N-fixing legumes in rotation and lastly from improvements in water harvesting.

In a rice-maize system in NW India, grain yields of conventional transplanted rice were 5–7% higher compared to ZT direct-seeded rice (DSR). Grain yield of following maize under CA was 14.2% higher compared to conventional till maize after conventional puddled transplanted rice. Gradual improvement in soil physical health in CA system resulted in higher and stable crop productivity and profitability over conventional system. Another study at Karnal (Haryana) in NW India showed that system productivity under CA based RW system was 14% higher compared to conventional system. Irrigation water and energy use were 50% and 43% lower in CA-RW-mungbean compared to conventional RW system. Organic carbon increased by 22%. Diversification of conventional RW system with CA-maize-wheat-mungbean system increased system productivity by 12%, reduced water and energy use by 71% and 51% (Choudhary et al., 2018a). Higher yields with crop residues application result from increased infiltration and improved soil properties, increased soil organic matter and earthworm activity and improved soil structure after a period of 4-7 years. Increased yield due to retention of crop residues can be attributed to: (a) conservation of soil moisture and nutrients; (b) improved soil water infiltration; (c) improved soil biological activities and nutrient cycling; (d) better weed control; (e) improved soil quality through increased soil organic matter concentration; and (f) regulation of soil temperature thereby minimizing high temperature effects during wheat maturity. Inclusion of grain legume (mungbean, MB) in the rotation had no effect on rice and wheat yield but nominally increased overall system productivity. If MB yield is converted into rice or wheat equivalent, then the gain on system yield with MB would be much higher. CA increased the yield of wheat by 11-30% over no residue in RW system of NW India.

Conclusion

The CA approach for managing agro-ecosystems is of paramount significance in improving soil health, sustained productivity and maintaining natural biodiversity. CA practices in relation to the specific management regimes have shown noteworthy improvement in soil physico-chemical properties *viz*., soil aggregation, density, penetration, thermo-regulation, water and nutrient interaction for maintaining a favourable soil-water-plant continuum. CA practices had a positive impact on soil organic C–pools, macro–aggregate formation, and carbon stock in aggregates. The CA systems could maintain higher passive C–pool over CT and thus upgrade the quality of organic carbon, which persist longer in the soil. Soil health has no constant and ubiquitously applicable value for the function of nutrient cycling and even less so in view of other soil functions. Consequently, assessments of soil properties and recommended management actions will likely need to be site-specific, bearing in mind that the plasticity of the supply of functions and the demand for them, differ from one place to another. Many changes in soil quality become apparent after many years (5yrs or more). The assessment of soil health requires quantification of critical soil attributes (physical, chemical and biological). Embracing CA practices are crucial for efficient soil C management and for sustainability of the rice–based systems in the region.

References

Blair, G.J., Lefroy, R.D.B. and Lisle, L. (1995). Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. Aust. J. Agric. Res. 46, 1459-1466.

Choudhary, M., Datta, A., Jat, H.S., Yadav, A.K., Gathala, M.K., Sapkota, T.B., Das, A.K., Sharma, P.C., Jat, M.L., Singh, R. and Ladha, J.K. (2018a). Changes in soil biology under conservation agriculture based sustainable intensification of cereal systems in Indo-Gangetic Plains. Geoderma, 313, 193-204,

Choudhary, M., Jat, H.S., Datta, A., Yadav, A.K., Sapkota, T.B., Mondal, S., Meena, R.P., Sharma, P.C., Jat, M.L. (2018b). Sustainable intensification influences soil quality, biota, and productivity in cereal-based agroecosystems. Appl. Soil Ecol., 126, 189-198.

Corsi, S., Friedrich, T., Kassam1, A., Pisante, M. and João de Moraes Sà. (2012). Soil organic carbon accumulation and greenhouse gas emission reductions from conservation agriculture: A literature review. Integrated Crop Management Vol.16. Food and Agriculture Organization of the United Nations (FAO), Rome.

Gathala, M.K., Kumar, V., Sharma, P.C., Saharawat, Y.S., Jat, H.S., Singh, M., Kumar, A., Jat, M.L., Humphreys, E., Sharma, D.K., Sharma, S. and Ladha, J.K. (2013) Optimizing intensive cereal based cropping systems addressing current and future drivers of agricultural change in the north-western Indo-Gangetic Plains of India. Agric. Ecosys. Environ. 177, 85–97.

Gathala, M.K., Ladha, J. K., Kumar, V., Saharawat, Y.S., Kumar, V., Sharma, P.K., Sharma, S. and Pathak, H. (2011). Tillage and crop establishment affects sustainability of south asian rice-wheat system. Ag. J. 103, 661-672.

Ghosh, S., Wilson, B., Ghosal, S., Senapati, N. and Mandal, B. (2012). Organic amendments influence soil quality and carbon sequestration in the Indo-Gangetic plains of India. Agric. Ecosys. Environ. 156, 131–141.

Govaerts, B., Verhulst, N., Castellanos-Navarrete, A., Sayre, K.D., Dixon, J., Dendooven, L. (2009). Conservation agriculture and soil carbon sequestration: between myth and farmer reality. Crit. Rev. Plant Sci. 28, 97–122.

Jat, H.S., Datta, A., Sharma, P.C., Kumar, V., Yadav, A.K., Choudhary, M., Choudhary, V., Gathala, M.K., Sharma, D.K., Jat, M.L. and Yaduvanshi, N.P.S. (2018). Assessing soil properties and nutrient availability under conservation agriculture practices in a reclaimed sodic soil in cereal-based systems of North-West India. Arch. Agro. Soil Sci. 64, 531-545.

Ladha, J.K. Yadvinder -Singh, Erenstein, O, Hardy, B. (2009). Integrated Crop and Resource Management in the rice-wheat systems of south Asia. International Rice Research Institute, Los Banos, Philippines. 395 p.

Laik, R., Sharma, S., Idris, M., Singh, A,K., Singh, S.S., Bhatt, B.P., Saharawat, Y., Humphreys, E. and Ladha, J.K. (2017). Integration of conservation agriculture with best management practices for improving system performance of the rice–wheat rotation in the Eastern Indo-Gangetic Plains of India. Agric. Ecosys. Environ. 195, 62-82.

Nandan, R., Singh, V., Singh, S.S., Kumar, V., Hazra, K.K. and Nath, C.P. (2019). Impact of conservation tillage in rice–based cropping systems on soil aggregation, carbon pools and nutrients. Geoderma 340, 104-114.

Nath, C.P., Das, T.K., Bhattacharyya, R., Pathak, H., Paul, S., Chakraborty, D. and Hazra, K.K. (2017). Nitrogen effects on productivity and soil properties in conventional and zero tilled wheat with different residue management. Proc. Natl. Acad. Sci., India, Sect. B Biol. Sci. 89(C).

Pacala,S. and Socolow, R. (2004). Stabilization wedges: solving the climate problem for the next 50 years with current technologies. Science. 305, Issue 5686, pp. 968-972 DOI: 10.1126/science.1100103

Parihar, C.M., Parihar, M.D., Sapkota, T.B., Nanwal, R.K., Singh, A.K., Jat, S.L., Nayak, H.S., Mahala, M.D., Singh, L.K., Kakraliya, S.K., Stirling, C.M. and Jat, M.L. (2018). Long-term impact of conservation agriculture and diversified maize rotations on carbon pools and stocks, mineral nitrogen fractions and nitrous oxide fluxes in Inceptisol of India. The Sci Total Environ. 640-641, 1382-1392.

Singh, V.K., Yadvinder-Singh, Dwivedi, B.S., Singh, S.K., Majumdar, K., Jat, M.L., Mishra, R.P, Rani, M. (2016). Soil physical properties, yield trends and economics after five years of conservation agriculture based rice-maize system in north-western India. Soil Till. Res. 155, 133–148.

Umar, B.B., Aun, J.B., Johnsen, F.H., and Lungu, O.I. (2011). Options for improving smallholder conservation agriculture in Zambia. J. Agric. Sci. 3, 50-62.

Venkatesh, M. S., Hazra, K. K., Ghosh, P. K., Praharaj, C. S. and Kumar, N. (2013). Long-term effect of pulses and nutrient management on soil carbon sequestration in Indo-Gangetic plains of India. Can. J. Soil Sci. 93: 127-136.

Yadvinder-Singh., Thind, H.S. and Sidhu, H.S. (2014). Management options for rice residues for sustainable Productivity of rice-wheat cropping system. J Res Punjab agric

6 Conservation Agriculture and Climate Change

Globally, agriculture faces the triple challenge of increasing production to meet the growing food demand, adapting to changing climatic conditions whilst reducing agricultural GHG emissions where possible. Three major GHGs, which are responsible for global warming are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) and agriculture accounts for 33 percent of global GHGs emissions to the atmosphere which has emerged as the most prominent environmental issue all over the world. Agriculture, crucial for ensuring food, nutritional and livelihood security of both Africa and South Asia, is exposed to the stresses arising from climate change due to increase in global GHG emissions. With future climate change, increased temperatures, erratic precipitation patterns, greater extent and frequency of extreme weather events (periods with excess rainfall and prolonged drought), together with the increase in temperature, will negatively impact the agriculture productivity, and there is a fear of serious food insecurity in the coming years in West African countries and India. In West Africa, climate variability is driving agro-climatic zones towards aridification from north to south. Added to this, climate projections indicate that regional warming in Africa is likely to proceed at a faster rate than global averages resulting, under medium scenarios, in a temperature increase of 2°C by the end of this century (Niang et al., 2014).

The climate change places tremendous pressure on agricultural systems that are largely small-scale, low input, and rain fed and which are already struggling to feed the population. Many developing countries including West Africa and India are likely to see a significant decrease in food grain production because of heat stress and water shortage. In dry areas, the absolute amount of rain is expected to decrease by 20% due to climate change. In South Asia, it is predicted that the annual average maximum temperature may increase by 1.4–1.8 °C in 2030 and 2.1–2.6 °C in 2050, and thus, heat-stressed areas in the region could increase by 12% in 2030 and 21% in 2050 (Tesfaye et al. 2017). By 2050, due to climate change induced heat and water stress yields are likely to decrease by 17% for maize, 12% for wheat, and 10% for rice (Asian Development Bank, 2009). The IPCC predicts maize yield losses of between 18% and 30% in southern Africa by 2050 and also mentions the possibility of sorghum yields declining.

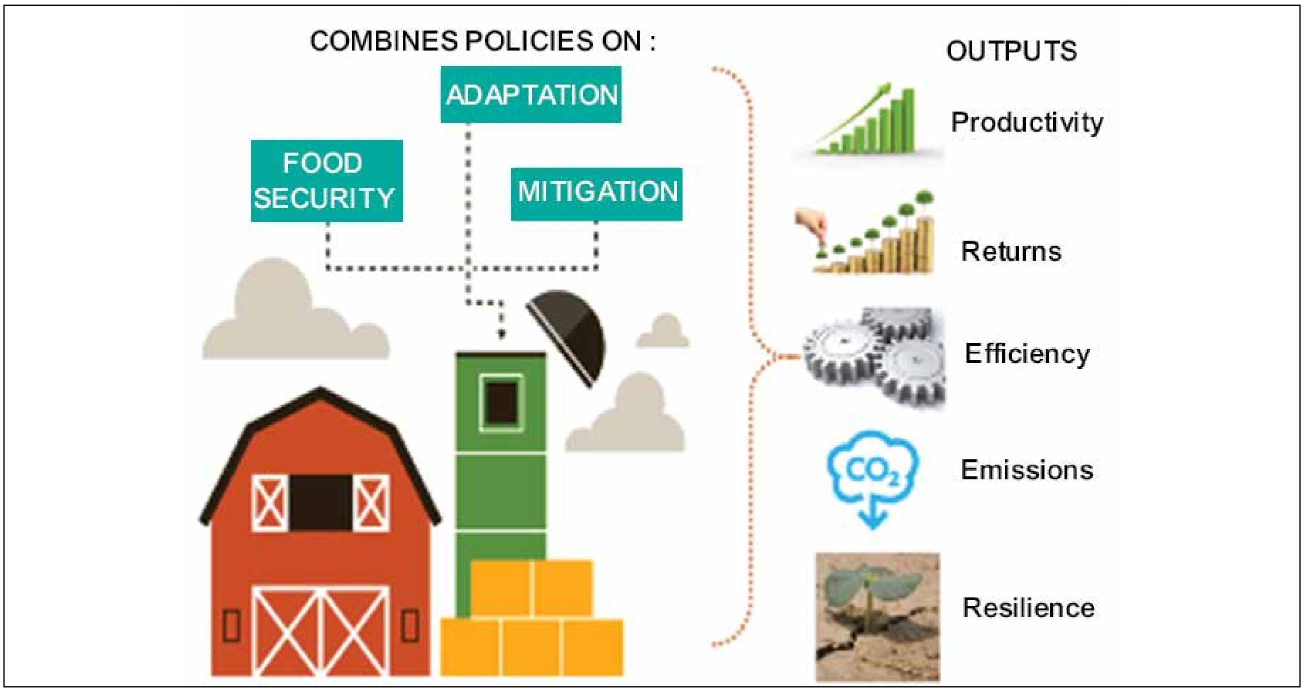
Besides its impact on crop yields and production, climate change also affects the natural resources, primarily land and water that are fundamental to agricultural production. The growing reliance of farmers on groundwater to cope with climate-induced drought has already led to a rapid decline in the groundwater table, and it may worsen further due to increased climatic variability in future (Fishman 2018). Projections claim that almost half of the Indo-Gangetic Plains (IGP), the major food basket of the South Asian region, may become inappropriate for wheat production by 2050 as a result of heat stress (Ortiz et al. 2008). With its impact on agricultural production and natural resources, climate change will bring greater fluctuation in crop production and food supplies, and will aggravate the situation of food insecurity and poverty in developing countries, which adversely affects the livelihoods of millions of people in the region (Wang et al. 2017; Aryal et al. 2019b). Climate resilient cropping systems are therefore required to adapt to the increasing threats of climate change projected for Africa and other developing countries and to better manage current climate variability. In view of these challenges, increased attention is being paid to innovative approaches to food production in developing countries, which protect the soil whilst increasing resilience to climatic variability. One such intervention is conservation agriculture (CA). This has received much acclaim as a cost saving, soil- and water-conserving set of practices in many farming systems around the world. CA is seen by many as having an important role to play in strategies contributing to global food security and improved resilience and adaptation to climate change. Several studies have emphasized the contributions of CA to reducing GHG emissions (Dendooven et al., 2012; Verhulst et al., 2012) and increasing soil carbon sequestration (UNEP, 2013).

It is not only important to adopt strategies to mitigate climate change, but it is also necessary to adopt practices which increase the resilience of agricultural ecosystems to reduce their vulnerability to the potential consequences of global warming, favouring the adaptation of crops to new climatic scenarios. Some of the mitigation strategies are: (i) shift to low C economy, (ii) reducing use of fossil fuels and (ii) reduce area under flooded transplanted rice, (iv) precision nutrient and water management. The adaptation strategies include: (i) identification of heat stress-resistance genes through biotechnological techniques, (ii) identifying genotypes tolerant to biotic (pest and diseases) and abiotic (drought, salinity) stress, (iii) sequester C, (iv). afforestation, (v) precision agriculture practices to improve water and nutrient use efficiencies, etc. One such intervention is conservation agriculture (CA) or climate smart agriculture. This has received much acclaim as a cost saving, soil- and water-conserving set of practices in many farming systems around the world. Several studies have emphasized the contributions of CA to reducing GHG emissions and increasing soil carbon sequestration (UNEP, 2013). CA is seen by many as having an important role to play in strategies contributing to global food security and improved resilience and adaptation to climate change. (Thierfelder et al., 2014; Nandan et al., 2019).

6.1 Climate Smart Agriculture and Conservation Agriculture

Climate SMART (sustainable management of agricultural resources and techniques) agriculture is an approach of crop production that deals with the management of available agricultural resources with latest management practices and farm machinery under a particular set of edaphic and environmental conditions(see https://csa.guide/csa/ what-is-climate-smart-agriculture). Climate-smart Agriculture (CSA) as defined by the FAO is agriculture that sustainably increases productivity, enhances the resilience (adaptation) of livelihoods and ecosystems, reduces and/or removes GHGs (mitigation) and enhances the achievement of national food security and development goals. The climate-smart technologies deliver three benefits: a) adapt to the effects of climate and be of increased resilience; b) mitigate climate effects by sequestering carbon and reducing GHG emissions; and c) sustainably increase/reduce intra year variation in productivity and income of the farmers. The CSA has three pillars i.e. food security; adaptive capacity; and mitigation potential (Fig. 6.1). The CSA consists of two interlinked concepts; one, it refers to farming practices that are resilient to climate and weather change, and second, farming is done in such a way so as cause minimal further climate change. There are many options to reduce the negative impacts of climate change on agricultural systems, make them resilient to climate change and reduce agricultures' impact on climate change. Options range from a simple change in sowing date to escape the impact of climate change on the cropping systems and adoption of CSA practices. Photovoltaic or solar-powered drip-irrigation systems combine the efficiency of drip irrigation with the reliability of a solar-powered water pump. The solar powered renewable energy pumps are preferable because they neither use fossil resources nor emit GHGs. The CSA includes several portfolios of interventions such as (i) water-smart agricultural practices (rainwater harvesting, laser land levelling, micro-irrigation, raised bed planting, crop diversification, alternate wetting and drying in rice and direct seeded rice); (ii) weather-smart activities (ICT-based agro-met services, index-based insurance, stress-tolerant crops and varieties); (iii) nutrient-smart practices (precision fertiliser application using Nutrient Expert decision support tools, GreenSeeker and Leaf Color Chart, residue management, legume catch-cropping); (iv) carbon smart (residue management, cover cropping, zero tillage, agro-forestry which capture atmospheric CO_2); (v) energy-smart (zero tillage, residue management, legumes); and (vi) knowledge-smart activities (farmer-farmer learning, capacity enhancement on climate-smart agriculture, community seed banks and cooperatives). The use of high-yielding and stress-tolerant seed varieties/breeds, and the

Figure 6.1. Three pillars of climate smart agriculture and their effects on climate change



adoption of improved management practices stabilize and increase farm production even under adverse production conditions. Other CSA practices include integrated crop-livestock management, agroforestry, and improved water management and innovative practices such as better weather forecasting, more resilient food crops and risk insurance. Like CA, CSA is location specific and tailored to fit the agro-ecological and socioeconomic conditions of a location. Interventions that work in one area may not be applicable in another. Few African countries (e,g. (Zimbabwe) have a number of policies and strategies relevant to climate change, some of which support CSA.

Given the vulnerability of agricultural systems to climate change, CSA has been designated a priority area of scientific research and innovation in India under a project, known as National Innovations on Climate-Resilient Agriculture (NICRA, http://www.nicra-icar.in/). Similarly, in 2011, CGIAR research program on CCAFS has initiated a program called climate smart village (CSV) in South Asia. Nevertheless, CSA needs better integration into the development policies and schemes for effective implementation and sustainable impact at scale. The focus of CSA has been on the implementation of these field and farm practices and the ways that they can be improved to tackle the problem of climate change.

6.2 Conservation Agriculture and Climate Change Mitigation

Mitigation means avoiding the GHGs emissions via environmental and industrial measures and adaptation means managing the unavoidable through research and development. The multiple environmental benefits of CA include; reducing soil erosion (up to more than 90%), improving the soil health, increasing biodiversity, mitigating and adapting to climate change, among others.

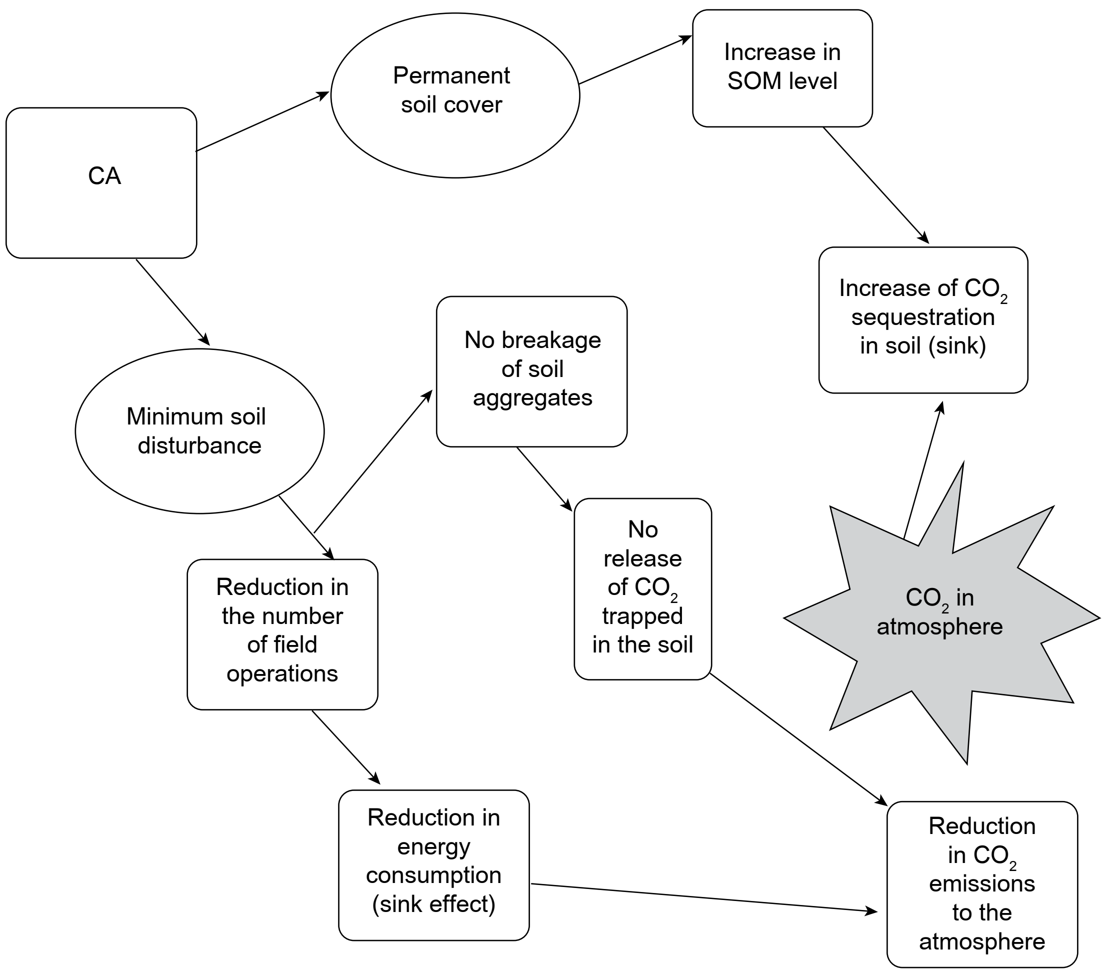
Climate change mitigation through CA is based on the three main factors (sink effect, reduction of emissions from the ground and reduction of emissions from the use of agricultural machinery). The sum of the first two processes, an increase in the carbon sink effect in the soil and a decrease in CO_2 atmospheric emissions from the soil, leads to a net increase of soil organic carbon (SOC). Figure 6.2 shows effect of conservation agriculture on carbon sequestration and GHG emissions.

Mitigation of GHGs emission from agriculture can be achieved by sequestering large amounts of C in soil and reducing the emissions of GHGs through adoption of CA practices and enhancing input-use efficiency. On the one hand, the changes introduced by CA (more crop residues as mulch and cover crop) increase the C in the soil through higher organic carbon inputs.

And on the other hand, the drastic reduction of tillage operations leads to reduction in the CO_2 emission resulting from energy savings through less fuel consumption and the reduction of the mineralization of the soil organic matter with the consequent markedly lower negative effect on climate change. N_2O emissions are more damaging to the environment than CO_2 which can be reduced by improving N use efficiency and cutting CH_4 emissions by limiting the extent of flooded rice cultivation. Precision N management and the introduction of grain legume crops in cropping systems, which fix nitrogen will reduce N_2O emissions. Improved soil health in CA systems lowers N fertilizer requirements, which means less potential for N_2O emissions. CA has a double effect on the reduction in GHGs concentration in atmosphere. CA increases C sequestration, and biodiversity, and reduces runoff and soil evaporation thus improving the WUE. In CA, emission of CO_2 by agriculture is decreased by reducing tillage and maintaining crop residues on the soil surface to increase C sequestration in the soil, especially when combined with the reduced burning of fossil fuels for field operations associated with reduced or ZT.

CA has been proven to substantially reduce GHG emissions through reduced diesel use and increased sequestration of C in the soil, by improving N use efficiency, and by reducing or eliminating the burning of crop residues and enhance its role as carbon sinks. The increased stability of the aggregates under CA allows a greater protection of the SOC against the attacks of the soil microbes, and protecting the "trapped" C within the aggregates, the CO_2 resulting from the mineralization processes of soil organic matter. The reduction of tillage also slows the decomposition of crop residues, storing the atmospheric CO_2 (fixed in the structure of the plant and returned to the ground in the form of crop residue) in the soil. In this way, the soil will have the function of storing atmospheric CO_2,

Figure 6.2. Flow diagram showing effect of conservation agriculture on carbon sequestration and greenhouse gas emissions



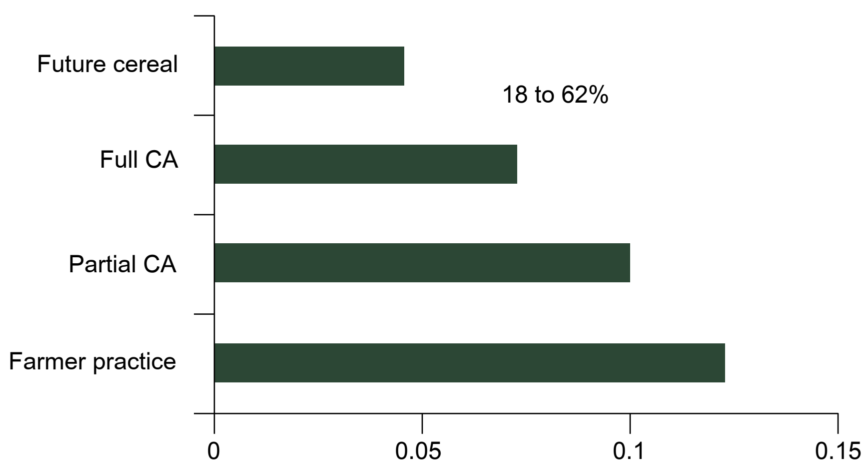
thus helping to mitigate the GHG emissions generated by other activities. In this way, the soil will store more atmospheric CO_2, thus helping to mitigate the GHG emissions generated by other activities. The lower the number of operations, the lower the fuel consumption. In the end, energy consumption in CA turns into CO_2 atmospheric emissions.

CA systems also mitigate climate change by decreasing in soil water evaporation and helps in saving electricity costs and reduction in GHG for energy production consumed in irrigation. CA involving ZT and surface managed crop residue systems are excellent opportunity to eliminate burning of crop residues which contribute to large amount of GHGs and large amount of particulate matter. In conventional practices, crop residue burning contributes significantly to CO_2 emissions and considerable loss of plant nutrients. In CA, crop residues serve as the biggest source of CO_2 sequestration and are believed to provide mitigation co–benefits through reduced GHG emission in CA. Studies showed that CA practices in rice (e.g. direct-seeding under ZT) reduced CH_4 emissions. The global warming potential (GWP) was lower for CA compared with conventional system. Potentially one-third of the carbon emitted in current fossil fuel use could be offset by implementing ZT and crop residue recycling in CA. Calculations show, by adopting of ZT for land preparation in wheat, farmers could save 36 liters diesel ha^{-1} equivalent to a reduction in 93 kg CO_2 emission ha^{-1} per season.

Adoption of CA practices in rice in Haryana could reduce total the global warming potential (GWP) for rice by 23% annually. Diversifying rice with maize in the dry season has potential to reduce GWP by 38%. On a system basis, CA-based rice–wheat and maize–wheat systems have potential to reduce GWP by 16–26% compared with business-as-usual conventional (Farmer practice) rice–wheat systems. With best agronomic management practices, including CA and cropping system diversification, the productivity of rice- and wheat-based cropping systems of South Asia increased substantially, whereas the GWP intensity (GWPi) decreased (Fig. 6.3). CA and crop diversification achieved a 104% increase in economic returns, 35% lower total water input, and a 43% lower GWPi (Ladha et al., 2015). CA-based MW system had significantly lower GWPi than in conventional RWS. A significant reduction in GWPi in CA-based MW system suggests that in areas where cropping system diversification is feasible there is also scope for mitigation of GHG emissions. Another study showed that a-based cereal systems reduced GWP by 16–26% or by 1.3–2.0 Tg CO_2 eq/yr compared with the conventional system. With the adoption of CA practices food security would not only be enhanced but also offset fossil fuel emissions at the rate of 0.5 Pg C/yr. CA has the potential to slow/reverse the rate of emissions of CO_2 and other GHG by reducing tillage and residue burning and improving N use efficiency. CA resulted in increases of 8% in RW system productivity, 23% in profitability, 31% in water use efficiency, while reducing the GWP by 40% compared with farmer's practice (Kakraliya et al. 2018).

Another study from North-West India show that CA-based RW system reduced CH_4 emission and

Figure 6.3. Global warming potential intensity – GWPi (kg CO2eq MJ^{-1}) in a rice-wheat system at Karnal Haryana (India)



resulted in the lowest global warming potential (GWP) ranging from -3301 to -823 kg CO_2-eq ha^{-1} $year^{-1}$ compared to 4113 to 7917 kg CO_2-eq ha^{-1} $year^{-1}$ in CT systems. The water footprint of RW production system was about 29% less in CA-based system compared to CT-based systems (Ref??). In CA systems, both rice and wheat yields were about 0.29 Mg ha^{-1} yr^{-1} more than CT system.

6.3 Conservation Agriculture and Carbon Sequestration

In agriculture CO_2 is assimilated during photosynthesis in crops and rangelands. Part of this C is released back into the atmosphere during plant and soil respiration or fire, part of it being stored in SOM and in harvested biomass and animal products, and part being liable to erosion and leaching as dissolved organic and inorganic carbon and methane (CH_4). The increase in carbon fixation in soil is also known as CO_2 sequestration. SOC sequestration was defined by Olson (2010) as "Process of transferring CO_2 from the atmosphere into the soil through plants, plant residues and other organic solids, which are stored or retained as part of the SOM (humus). On the one hand, the changes introduced by CA related to the C dynamics in the soil, lead directly to an increase in soil C and create sinks of C. On the other hand, the drastic reduction in the amount of tillage and the mechanical non-alteration of the soil, reduce CO_2 emissions derived from the energy saving and the reduction of the mineralization processes of the soil organic matter. Carbon sequestration describes long-term storage of CO_2or other forms of carbon to either mitigate or defer global warming and avoid dangerous climate change. Sequestration of SOC would: (i) help mitigate GHG emissions contributing to global warming and (ii) increase soil productivity and avoid further environmental damage from the unsustainable use of intensive tillage systems.

The largest contribution to mitigate climate change with the CA could be obtained from carbon sequestration and storage of atmospheric carbon in the soil. Other benefits of carbon sequestration are enhancement of SOC pool, advancing food security and improving the environment. Retention of crop residues, minimum tillage, soil conservation and erosion-control contribute to carbon sequestration in CA. Carbon farming, treading C credits is another economic benefit and is an important strategy to provide incentives for promoting adoption CA. As an indicator for soil health, SOC is important for its contributions to food production, mitigation and adaptation to climate change, and the achievement of the Sustainable Development Goals (SDGs). So, C sequestration is very important which must be looked into when you are talking of CA. The effectiveness of CA practices depends on factors such as climate, soil type, input resources and farming system. In CA, about 90% of the total mitigation arises from sink enhancement (soil C sequestration) and about 10% from emission reduction (Ortiz-Monasterio *et al*., 2010).

It is important to determine carbon sequestration rates for various agricultural land management systems. The retention time of sequestered carbon in the soil (terrestrial pool) can range from short-term (not immediately released back to atmosphere) to long-term (millennia) storage. The sequestrated SOC process should increase the net SOC storage above the previous pre-treatment baseline levels and result in a net reduction in the CO_2 levels in atmosphere. The measurement of soil carbon sequestration includes actual changes in a specific part of a terrestrial (soil) pool.

CA is reported to sequester carbon in soil at a rate of about 0.5 t/ha/year; thus, the world is sequestering about 90 million tons of carbon per year on the 180 million hectares of arable and permanent crop land that is now under CA. It has been estimated that conversion of all cropland to CA globally could mitigate C emission to the extent of 1833 Mt CO_2eq yr^{-1}. In order to estimate the sequestered CO_2, on the basis of the amount of organic C fixed in the soil, it has been taken into consideration that one ton of C generates 3.7 tons of CO_2, through microbiological oxidation processes in the soil.

The 4 per 1000 Initiative was launched by France in 2015, during the 21st Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change. It promotes an innovative model for mitigating climate change, through the annual increase in soil organic C by 0.04% in the top 30-40 cm of agricultural soils. The increase rate of CO_2 in the atmosphere could be reduced, while improving soil health, reducing soil erosion, combating climate change and strengthening essential ecosystems and contributing to food security. The COP23 in 2017 in Bonn (Germany) took a major step to prioritize agriculture in climate action and realize new strategies for adaptation and mitigation in the agriculture sector to reduce emissions.

Results from different studies indicate that not only is soil organic matter improved, but the system can support current or higher yields, and reduce associated GHG emissions.

6.4 Conservation Agriculture and Climate Change Adaptation

The term "adaptation" refers to all adjustments that need to be made in an agricultural system to better respond to actual or anticipated changes resulting from climate change, and taking advantage of the opportunities given by the new climatic scenarios. Adaptation means looking for strategies at the local level to respond to a global problem. It is not only important to adopt strategies to mitigate climate change, but it is also necessary to adopt practices which increase the resilience of agricultural ecosystems to reduce their vulnerability to the potential consequences of global warming, favouring the adaptation of crops to new climatic scenarios. The options for adapting crops to the scenarios caused by climate change will increase the resilience of the ecosystems in which they are developing. The term "resilience" refers to the responsiveness of the medium to a disturbing agent or a harmful condition, minimizing the impact of such a situation and adapting to it. CA is a good strategy not only to mitigate climate change, but also to adapt agricultural ecosystems to their effects, by increasing crop resilience facing climatic variations. The advantages offered by CA related to adaptation to climate change will be particularly interesting in ecosystems with a decrease in water resources availability or in those regions, in which, due to the increase of extreme precipitation events, the phenomena of runoff are increased.

CA reduces erosion and improves the fertility of the soil, allowing the crop to have more water in dry periods. Adoption of CA will not only mitigate climate change, but also adapt agricultural ecosystems to their effects, by increasing crop resilience facing climatic variations. The implementation of CA will reduce erosion and thereby improve the soil health, allowing the crop to have more water in dry periods. All this makes the responsiveness to climate changes greater and therefore crops under CA systems have a better capacity of adaptation. The ways to respond could be, either mitigating them directly, or creating a response in the environment and natural resources on which it depends, counteracting the negative effects.

CA systems reduce water evaporation into the atmosphere and improve the use of available water in the soil by the crops. As a result, rainfed crops can better withstand stress conditions. This positive effect is especially noticeable in dry years. Crop rotation also offers other advantages that help the ecosystem to be more and better prepared for the variety climatic scenarios caused by global warming, and, therefore, to be more sustainable. Crop rotations can reduce the risk created by extreme weather events such as droughts or floods and their negative effects, since their incidence does not equally affect all crops. In this case, rotation represents a way to diversify risk. The rotation of crops promoted by CA increases the resilience of the agricultural ecosystem, improving soil properties in general, while increasing the crop potential to obtain higher yields. Residue management in zero till systems (surface retention) improved soil health, reduced GHG emission equivalent nearly 13 t/ha (Mandal et al., 2004) and lowered leaf canopy temperature at grain filling stage mitigating terminal heat stress in wheat (Gupta et al., 2010; Jat et al., 2011). The area under CA is increasing globally though at a slow pace presently estimated around 108 m ha (Derpsch and Friedrich, 2009) and in South Asia nearly 3.9 m ha. In view of crop residue significance in CA the nutrient management research assumes vital role for improving soil and crop productivity along with environmental quality.

Studies from north-west India showed that crops under CA can adapt to aberrant weather conditions such as flooding (Fig. 6.4a) and terminal heat stress (Fig. 6.4b) therebyyielding markedly higher than that under conventional agriculture.

Figure 6.4. CA in Maize Systems: Adapting climate risks (200+ mm in 3 days in end of June 2017) in Haryana, India(Left) and CA in wheat systems: Adaptation to terminal heat stress (left) in comparison to conventional agriculture (Right).

Conclusion

Climate change is likely to threaten the food security and livelihoods of millions of people in the World. Rising temperatures, increased climate variability and extreme weather events could significantly impact food production in the coming decades. Crop yields and consequently food production in many areas are actually falling. Agriculture in West Africa is known to be vulnerable to climate change due to high climate variability, high reliance on rain-fed agriculture, and limited economic and institutional capacity to respond to climate variability and change. Therefore, there is a need for using modern science combined with indigenous wisdom of the farmers to enhance the resilience of modern agriculture to climate change. With increased efficiency of the production system, precision-conservation agriculture can act as one of the strategies for adaptation to uncertain climatic conditions as well as reducing environmental foot prints while improving food production on sustainable basis. All countries in Asia and Africa should frame national-level policies and incentives that would encourage farmers to climate change adaptation through developing and adopting CA practices. There is a need to frame policies and incentives that would encourage farmers to sequester carbon in the soil and thus improve soil health, and water use and energy more efficiently. There is a strong need to build the capacity of farmers to adapt their technical and traditional knowledge and agricultural practices to strengthen resilience of both the population and the agriculture and livestock that feed them. Though several adaptations options are available in agriculture, not all of them can be applied to all location, as they are mostly location-specific. We need to invest in CA that understandably increases productivity, enhances resilience (adaptation), reducers/removes GHGs (mitigation) wherever possible, and enhances food security. Institutions at the international and national levels need to work in cooperation to deal with the challenge of climate change. New varieties that can tolerate climatic stresses need to be developed. Despite the availability of options for climate change adaptation in CA, inefficient institution and financing might hinder Indian as well as African agriculture to tackle climate challenges in the future. Of the impact studies, the assessment of the impact of other climate variables except for temperature on crop yield is limited and thus an area for future research. The role of higher and tertiary education in CA and CSA includes research and development, networking and capacity-building in relation to both technical skills and knowledge diffusion.

References

Aryal, J.P., M.L. Jat, Tek B. Sapkota, Arun Khatri-Chhetri, Menale Kassie, Dil

Bahadur Rahut and Sofina Maharjan (2017). Adoption of multiple climate smart agricultural practices in the Gangetic plains of Bihar, India. Int. J. Climate Change Strat. Manage. 10, 407-427.

Asian Development Bank (2009). Understanding and responding to climate change in developing Asia. Mandaluyong City, Metro Manila, Philippines. http://hdl.handle.net/11540/2412.

Dendooven, L., Gutiérrez-Oliva, V.F., Patiño-Zúñiga, L., Ramírez-Villanueva, D.V., Verhulst, N., Luna-Guido, M., Marsch, R., Montes-Molina, J., Gutiérrez-Miceli, F.A., Vásquez-Murrieta, S., Govaerts, B. (2012). Greenhouse gas emissions under conservation agriculture compared to traditional cultivation of maize in the central highlands of Mexico. Sci. Total Environ. 431, 237-244.

Derpsch, R. and Friedrich, T. (2009), Development and current status of no-till adoption in the World, Proceedings on CD, 18th Triennial Conference of the International Soil Tillage Research Organization (ISTRO), Izmir, Turkey, June 15-19, 2009.

Fishman, R. (2018). Groundwater depletion limits the scope for adaptation to increased rainfall variability in India. Climatic Change 147, 195–209.

Gupta, R., Gopal, R., Jat, M.L., Jat, R.K., Sidhu, H.S., Minhas, P.S. and Malik, R.K. (2010). Wheat productivity in Indo-Gangetic plains of India during 2010: Terminal heat effects and mitigation strategies. PACA Newsl. 14, 1-4.

Ladha , J. K., Rao, A., Raman, A.K., Tirol-Padre, A., Dobermann, A. , Gathala, M., Kumar, V., Saharawat, Y.S., Sharma, S., Piepho, H.P., Alam, M.M., Liak , R., Rajendran, C. K. Reddy, C.K. Parsad, R. Sharma, P.C., Singh , S.K., Saha, A. and Noor, S. (2016). Agronomic improvements can make future cereal systems in South Asia far more productive and result in a lower environmental footprint. Glob. Climate Change 22, 1054-1074.

Mandal, K.G., Misra, A.K., Hati, K.M., Bandyopadhyay, K.K., Ghosh, P.K., Mohanty, M. (2004). Rice residue management options and effects on soil properties and crop productivity. J. Food Agric. Environ. 2, 224–231.

Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J. and Urquhart, P. (2014). Africa. In: Climate change: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Ortiz, R., Kenneth, D. Sayre, K., Govaerts, B., Gupta, R., Subbarao, G.V., Ban, T., Hodson, DF., Dixon, J.M., Ortiz-Monasterio, J.I. and Reynolds, M., (2008). Climate change: Can wheat beat the heat? Agric., Ecosyst. Environ. 126, 46–58.

Ortiz-Monasterio, I., Wassmann, R, Govaerts, B., Hosen, Y., Katayanagi, N. and Verhulst, N. (2010). Greenhouse gas mitigation in the main cereal systems: Rice, Wheat and Maize. 151-176 In Book. Climate change and crop production. CAB International (Ed. HYPERLINK "https://www.cabi.org/cabebooks/search/?q=ed%3a%22Reynolds%2c+M.+P.+%22" Reynolds, M. P). CAB International.

Tesfaye, K., Zaidi, P.H., Gbegbelegbe, S. et al. (2017). Climate change impacts and potential benefits of heat-tolerant maize in South Asia. Theor. Appl. Climatol. 130, 959–970.

Thierfelder, C., Matemba-Mutasa, R. and Rusinamhodzi, L. (2014). Yield response of maize (Zea Mays L.) to conservation agriculture cropping systems in Southern Africa. Soil and Tillage Research,146, 230–242.

UNEP (2013). The Emissions Gap Report 2013. United Nations Environment Programme (UNEP), Nairobi. http://www.unep.org/publications/ebooks/ emissionsgapreport2014/portals/50268/pdf/EGR2014_LOWRES.pdf (last accessed 28. 10.18.)

Verhulst, N., Govaerts, B., Sayre, K. D., Sonder, K., Perezgrovas, R., Mezzalama, M., & Dendooven, L. (2012). Conservation agriculture as a means to mitigate and adapt to climate change. A case study from Mexico. In: E. Wollenberg, A. Nihart, M.-L. Tapio-Bistro m, Grieg, and M. Gran (Eds.), Climate change mitigation and agriculture(pp. 287–300). Abington, UK: Earthscan.

Wang, F.H., Wang, X.Q., Sayre, K. (2004). Comparison of conventional, flood irrigated, flat planting with furrow irrigated, raised bed planting for winter wheat in China. Field Crops Res. 87, 35–42.

Wang, Z., Lin, L., Zhang, X. et al. (2017). Scenario dependence of future changes in climate extremes under 1.5 °C and 2 °C global warming. Sci Rep 7, 46432. https://doi.org/10.1038/srep46432.

Suggested additional reading material

Aryal, J. P., Sapkota, T. B., Rahut, D. B. and Jat, M. L. (2019). Agricultural Sustainability under emerging climatic variability: Role of climate smart agriculture and relevant policies in India. International Journal of Innovation and Sustainable Development. https://doi.org/10.1504/IJISD.2019.10020869.

Jat, M.L., Dagar, J.C., Sapkota, T.B., Yadvinder-Singh, Govaerts, B., Ridaura, S.L., Saharawat, Y.S., Sharma, R.K., Tetarwal, J.P., Jat, R.K., Hobbs. P. and Stirling, C. (2016) Climate change and agriculture: adaptation strategies and m

7 Application of Remote Sensing, Geographical Information System and Internet of things in Precision Agriculture

7.1. Application of Remote Sensing, Geographical information system

The remarkable developments in space borne remote sensing technology and its applications during the last four decades have established its immense potential for mapping and monitoring of various natural resources. Satellite Remote Sensing and Geographic Information System (GIS) offer great promise for natural resources management, with the ability to depict the spatial distribution of extent and monitoring capability.

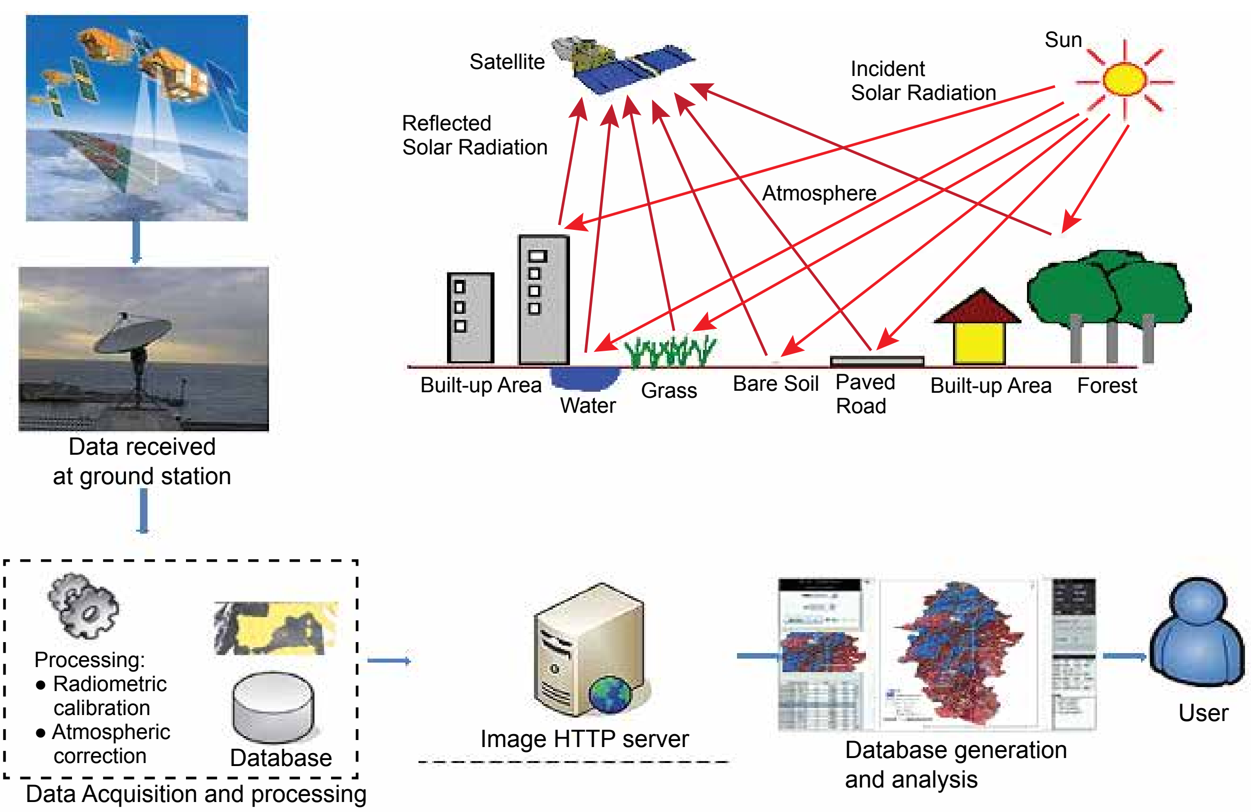
a. Remote Sensing

Remote Sensing is the process of sensing, identification, delineation, measurement of surface features and their processes from a distance without directly coming into physical contact. Our eyes are an excellent example of a remote sensing device. We are able to gather information about our surroundings by gauging the amount and nature of the reflectance of visible light energy from some external source (such as the sun or a light bulb), as it reflects off objects in our field of view.

The structure or vehicle on which remote sensing instruments is mounted are called platform. In general, three types of platforms are used for remote sensing:

I. Ground based (like ground vehicles and/or towers)

Figure 7.1. Stages in Remote Sensing and GIS



II. Airborne (like airplanes, helicopters and high-altitude aircrafts, balloons) and,

III. Space borne (like rockets, satellites and shuttle).

Remote sensing measures electromagnetic energy that is reflected, scattered or emitted by different surface features on the earth (Figure 7.1). The sensors (or cameras) mounted on remote sensing platforms detect and record the reflected or emitted energy from earth surfaces. The source of energy is either sun (passive remote sensing) or emitted by the sensor itself (active remote sensing). In remote sensing, the basic property which allows identification of the object is called 'signature'. For Example, ripening of papaya is indicated by yellow colour, and the signature in this case is yellow colour. After the energy has been re-elected by or emitted from the target, a sensor (mounted on a satellite orbiting in space) is required to collect and record the electromagnetic radiations which ranges from the shorter wavelengths (including gamma and x-rays) to the longer wavelengths (including microwaves and broadcast radio waves).

Characterization of satellite remote sensing systems

The properties of sensor and platform design have effect on the ability of sensor to record surface leaving radiations (signals). The following are the main common characteristics of different sensors which are used and are important for identification of the objects:

I. **Spatial resolution** refers to the size of the smallest object that can be discriminated by the sensors (or it specifies the pixel size of satellite images, covering the earth surface). The 'pixel size' denotes the area of ground covered by a single pixel in the resultant image.

II. **Spectral resolution** describes the ability of a sensor to define fine wavelength intervals. The finer the spectral resolution, the narrower the wavelength ranges for a particular band. Multi spectral refers usually to 5 – 10 discrete spectral bands with bandwidth about 50 – 400 nm, whereas hyperspectral refers to 100 - 200 spectral bands generally in continuum with relatively narrow band interval (5 – 10 nm).

III. **Radiometric resolution** included sensor's ability to discriminate very slight differences in reflected or emitted energy. The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in energy. Radiometric resolution is usually calculated in terms of binary bit-depth (2n), which refers to the number of grayscale levels, at which data are recorded by a particular sensor. The binary bit-depth is typically expressed in the following ranges of grayscale levels: 8-bit (28 colors and values varied from 0 to 255), 10-bit (210 colors and values varied from 0 to 1023) and 12-bit (210 colors and values varied from 0 to 4095).

IV. **Temporal resolution** is the revisit period, and is the length of time for a satellite to complete one entire orbit cycle (start and back to the exact same area at the same viewing angle).

Land imaging satellites, and processing of satellite data and its applications

Examples of few satellites are: LANDSAT (USA), SPOT (France), IRS (India), NOAA (USA), IKONOS (USA), RADARSAT (Canada), Sentinel (Europe), ENVISAT (Europe), JERS (Japan) and ALOS (Japan) etc. The first Landsat satellite was launched in 1972 and Landsat 8 was launched in February 2013. The satellite data of Landsat series is freely available.

Once the data is recorded by the sensor, either in pictorial form or electronically in numerical form, it is transmitted to ground based stations. The raw data is processed for radiometric, atmospheric and geometric corrections, to improve the quality of satellite image. The easily identified features on both ground and satellite images such as intersection of roads are used to geometrically rectify the image. These common points are called ground control points (GCPs). The satellite data can now be used for various applications like crop monitoring and yield forecasting, soil resource mapping, land use/ land cover, geology, disaster management, oceanography, urban or regional planning and water resource assessment etc. The satellite data is in pixel format. In general, vector data is preferred over raster data, which is heavy to store and takes comparatively longer time to analyse. An integration and analysis of various vector (or raster) layers, is performed using Geographic Information System (GIS).

b. Geographic Information System (GIS)

GIS helps us better understand our world so we can meet global challenges. By applying what we know of science and GIS to what we do not know, we can get to what we really need to know - how to enhance quality of life, and achieve a better future. GIS is a database management system which effectively store, retrieve, manipulate, analyse and display spatial information of both cartographic and thematic origin. This is a computer-based system which can handle large volumes of spatial data. Data has specific location (latitude-longitude) on the surface of the earth, derived from a variety of sources such as field surveys, aerial surveys, space remote sensing, in addition to the already existing maps and reports. GIS can also display the information in the pictorial format, for decision making and planning purposes.

GIS data: Spatial and Non-spatial data: Spatial data are the data or information that identifies the geographic location of features and boundaries on earth, such as natural or constructed features, oceans, and more. It is usually stored as coordinate and topology, and this data can be mapped. Non-spatial data is the attribute data. The spatial data is of two types: (i) **Raster data:** In the raster data model, the earth is represented as a grid of equally sized cells. An individual cell represents a portion of the earth, such as a square meter; and (ii) **Vector data:** In the vector data model, features on the earth are represented as points, lines and polygons.

Relationship between remote sensing and GIS

Remote sensing and GIS are integral to each other. Remote Sensing has the capability of providing large amount of data, which can be used in delineation and monitoring of various resources; and GIS has the capabilities of analyzing this voluminous data. Remote Sensing and GIS technologies can be used in developing an integrated decision support system, which can help the policy makers/managers to better understand the linkages among local, regional and global processes, take effective management decisions, and achieve the goals of sustainable development of the nation/state.

The use of GPS, Remote Sensing and GIS in agriculture

The use of GPS enabled guidance systems to guide the farm machines on the field bring several benefits including the reduction in overlap and missing leading to better productivity, increased working speed, workday expansion, and appropriate placement of spatially sensitive inputs.

Remote sensing of plant and soil status using integrated satellite, aerial, and field-level plant and soil-based sensor systems, can provide information on plant and soil nutrient and water status. Better systems and methods capable of measuring specific plant parameters (e.g., nutrient status, water status, disease and competing weeds), on a timely basis are becoming available, and are expected to provide information required to enhance crop modeling use, and thus improves within-season management. Real-time, on-the-go irrigation scheduling could be very effective in improving water management, when based on distributed networks of farm-level microclimate and soil water sensor stations, that feed into a microprocessor control system to manage irrigations according to rules pre-established by the producer. This effort must be supported by expanded agricultural weather networks, that incorporate greater spatial density, as well as by grower-friendly information delivery systems, that schedule irrigations in terms of pest management and marketing information. Input from distributed weather networks must be integrated with other information from remotely sensed and ground-based sources to effectively contribute to on-farm and irrigation district decision support processes. The use of remote sensing and GIS is explained below:

i. **Crop growth monitoring using spectral vegetation indices:** The Indices based on spectral vegetation characteristics derived from remotely sensed data, are correlated with crop health status, and can be used for growth monitoring and yield estimations. The spectral vegetation indices, calculated as the ratio of various bands or combinations of spectral bands, are related to a number of vegetation properties including yield. The underlying principle of these empirical spectral indices is that they are affected by the fraction of photosynthetically active radiation absorbed by the vegetation. Previous studies have related yield with spectral vegetation indices (like Normalized Difference Vegetation Index, NDVI) at a specific growth stage (e.g. vegetative and reproductive stages) during the growing season or with cumulative values of spectral vegetation indices during the entire growing season.

ii. **Detection of abiotic and biotic stresses in crops using remote sensing:** Field scale assessment of continuous crop condition is time-consuming, laborious and location specific, but remote sensing provides an effective substitute to field sampling for crop condition monitoring. Moreover, it can give continuous coverage of a large area. Multi- and hyper-spectral images have been used to detect abiotic stresses in agricultural crops and horticultural fruits. Water and nutrient constraints are the major abiotic stresses for crops, which adversely affect plant growth. The crop water stress is detected as reduction in soil water content, or from the physiological responses of the plant to water deficit. Soil moisture is generally less sensitive indicator of stress than plant water status which measures the response of a plant to the combined effects of soil moisture availability, evaporative demand, internal hydraulic resistance, and uptake capacity of the plant-root interface. A number of indices (i.e. Normalized Difference Vegetation Index, NDVI and Normalized Difference Water Index, NDWI) based on the visible and red edge spectral region have been developed for detecting water stress in crops.

The limitation of any essential plant nutrient can also results in different stress-induced responses, such as restricted shoots and roots growth, early defoliation of older leaves and decreased biomass yield as described in many studies. The estimation of plant nutrient needs, based on leaf optical properties such as fluorescence, reflectance and transmittance is gaining wide attention in agriculture. A number of studies have used the hyper-spectral data for detecting nutrient stress in plants.

Multispectral radiometers can also be used for the detection of biotic (pest and diseases) stresses. It was found that the band centered at 694 nm and the vegetation indices derived from bands centered at 800 and 694 nm were identified as most sensitive to damage, due to greenbug (Schizaphis graminum) infestation in wheat, and broad Landsat TM bands and derived vegetation indices also showed potential for detecting the stress. Several studies have demonstrated the utility of hyperspectral in diagnosing the pest and disease infestations in different crops. Their were significant differences in reflectance among pest infestations at wavelengths of 755 and 890 nm.

iii. Crop land suitability: Land Suitability Analysis is a GIS-based process applied to determine the suitability of a specific area for considered use. The Spatial Analytical Hierarchy method is among the best method, which is suitable for carrying out these kinds of analysis. The major parameters generally considered for suitability analysis are slope, soil texture, drainage, soil fertility (pH, electrical conductivity, organic carbon, macro and micronutrients), and ground water quality for irrigation. The weightage for each parameter is computed using the multiplicative method, followed by calculation of combined weightage which is expressed as Cumulative Suitability Index (CSI) of all the parameters. The area suitable for growing a specific crop is defined using CSI. The study suggested that depending upon the limitations and potential, marginally suitable area of a crop may be brought under alternative crops for achieving sustainable development.

iv. Prediction of soil properties using spectral algorithms: A variety of remote-sensing and proximal techniques have been used in different parts of the world for prediction of soil properties, using multispectral and hyperspectral remote sensing data and spectroradiometer. Mass spectroscopy (MS), nuclear magnetic resonance (NMR), visible (VIS), near infrared (NIR) and mid infrared (MIR) spectroscopy), are considered as possible alternatives to enhance or replace conventional laboratory methods of soil analysis. Various spectroscopic techniques have been used in the VIS, NIR and MIR regions for estimating pH , soil organic carbon content, soil colour, electrical conductivity, available nitrogen content, carbonate content and cation exchange capacity, available P and K contents. These are proximal sensing techniques used for prediction of soil properties. Quick bird and Landsat ETM+ for estimating EC and the Landsat for iron content in soil.

v. Remote monitoring of fields: Different types of environmental and soil parameters like temperature, moisture, humidity andsoil pH, etc. can be transferred through wireless system network (WSN) for further processing and analysis.

7.2. Use of Internet of Things (IoT)

The Internet of Things (IoT) is the network of devices such as vehicles, and home appliances that contain electronics, software, actuators, and connectivity which allows these things to connect, interact and exchange data (Wikipedia). In this chapter we shall include agricultural management and devices used in agriculture crop production with special reference to CA.

Current challenges in agriculture are:

a. Need for integrated information, Agri Library;

b. Reduced income of Farmers;

c. No protection against monsoon failure and natural calamities;

d. Market fluctuations;

e. Non availability of current cropping pattern to plan imports, or advise cropping pattern to farmers;

f. Crop insurance implementation issues;

g. Reducing man power availability in farms;

h. No 3PL/4PL logistics for both inputs and produce: Lead logistics providers (LLPs), also referred to as fourth-party logistics (4PL) providers, have a broad role within the supply chain. They assume many of the same roles as third-party logistics (3PL) providers, but have much broader responsibility and accountability in helping the customer reach its strategic goals.

i. Information on soil analysis; and

j. Advice on fertigation.

a. Application of IoT in agriculture (Fig. 7.2)

i. Farm Management and Information APP

ii. Device Control & Management

iii. Agricultural pump control and irrigation

iv. Poly House – Green house

v. Spraying

vi. Machinery – Automation Bots

vii. Driverless tractor

viii. Tractor monitoring

Figure 7.2. Applications of IoT in agriculture

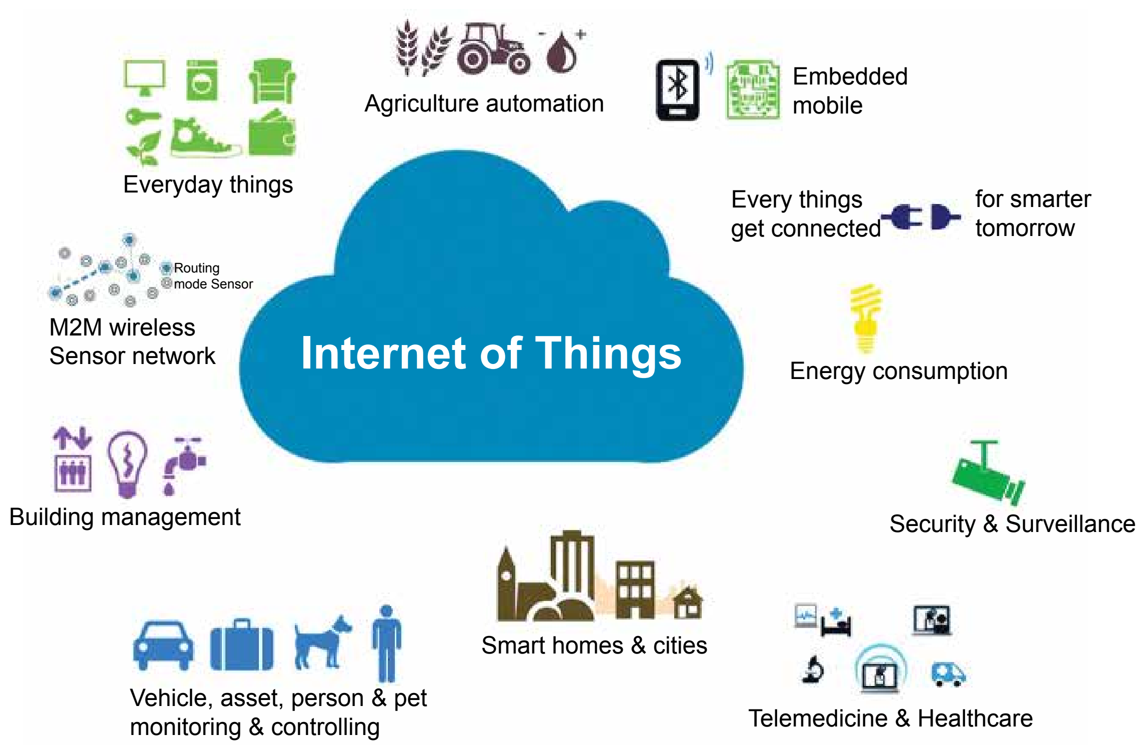
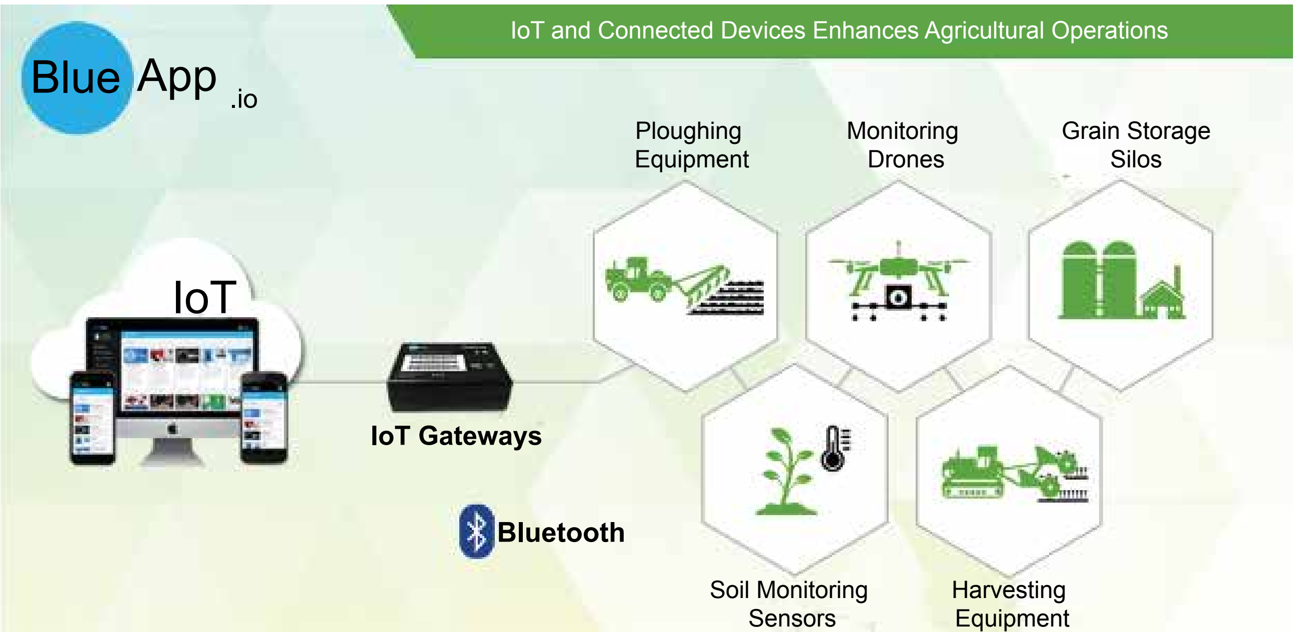


Figure 7.3. IoT Solutions for agriculture operations



ix. Drones, CanBus

x. Information Apps

xi. Agriculture information, and

xii. Mandi, buyer and seller, Marketing.

a. Administrative Solutions – The Phase I

Cropping pattern for each agricultural farm/ land depends on resources available, soil analysis records, water, fertigation and pest management details (Fig. 7.3).

b. Automation Solutions – The Phase II

Better water and fertigation management of each agricultural farm depends on:

i. **Water level measurement:** Water level in farm, water level in canal, tank and tube well

ii. **Fertigation Management:** Pump starter, **solenoid valves, blowers**

iii. **Environmental Information:** Temperature, humidity, atmospheric pressure, rain, wind speed and/direction, sunlight and radiation.

iv. **Network field sensors (Communication):** GSM/GPRS, ISM, WIFI, LORA, Satellite, Wired Sensors/Actuators, wireless Sensor

Automation/Sensors Based Machinery for precision agriculture include:

i. Laser/Pnuematic/Hydraulic based machinery

a. Combine sensors (GPS for area measurement, and sensors for yield and grain moisture measurements)

Figure 7.4. Use of IoTs for sustainable agriculture

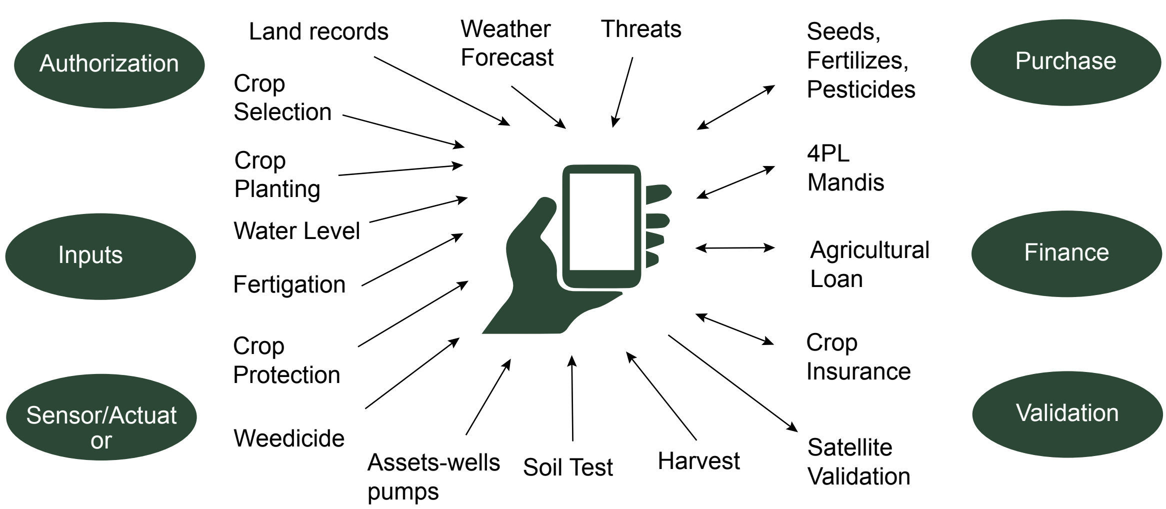
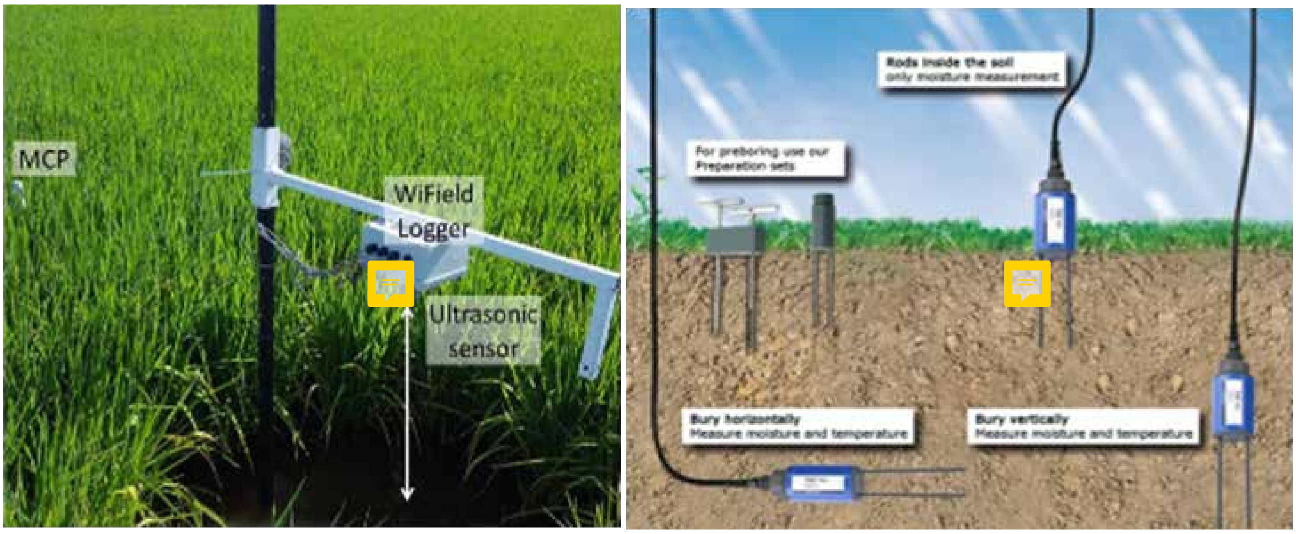


Figure 7.5. Soil Moisture Measurement using TDR



   b. Vehicle Guidance: Satellite navigator

ii. Plant Sensors: Visible/NIR reflectance

iii. Soil Sensors: EC sensor, compaction sensor and pH sensor (Fig. 7.5)

iv. Crop Sensors: This is one practical and affordable technology which can be given in the hands of a common farmer/service provider to access in-season crop nutrient and irrigation needs. Information can be used to make non-subjective decisions regarding the amount of fertiliser to be applied to the crop, resulting in more efficient use of fertiliser and better environment.

v. Use of Drone/UAV in agriculture

Wireless Sensor Network (WSN) for automated irrigation systems

In developing countries most of the irrigation systems are operated manually. Considering the current water and labor shortage situations, the automated sensing system will be most appropriate. The advancement in sensing and communication technologies has significantly brought down the cost of wireless sensors for their wide spread deployment in the irrigation systems. The wireless sensors are cheap enough for wide spread deployment in the form of a mesh network and offers robust communication through redundant propagation (Akyildiz and Wang 2005). The irrigation systems can be automated through information on volumetric water content of soil, using infrared thermometers, thermal imaging and crop water stress index using dielectric moisture sensors, instead of a predetermined irrigation schedule at a particular time of the day and with a specific duration. This method just opens the valve and supply water to plants when volumetric content of soil will drop below threshold value. Smart irrigation systems can optimize water levels based on soil moisture and weather predictions. This gateway permits the automated activation of irrigation, when the threshold values of soil moisture and temperature is reached. The WSNs can improve soil and crop monitoring and can raise the efficiency, productivity and profitability of the business while reducing its vulnerability towards climate variability and water deficit. The irrigation system can be combined with IoT for making use of water very efficiently. IoT helps to access information and make major decision-making process by getting different values from sensors. Wireless technology has a positive impact on the costs and efficiency of anything from home Internet installations, to the operations of large corporations worldwide. Obvious advantages of wireless transmission over wired one are their feasibility of installation in places, where cabling is impossible, and the significant reduction in cost and simplification in wiring and harness. Presently, sensors are available which can sense the depth of water especially in puddled transplanted rice and can save water. Similarly, MPS6 sensors could be used in automated irrigation system, for both rice and wheat under SSDF and flood conditions (H.S. Sidhu, Personal Communication).

Skills required for using IoT

Agriculturist and Agri engineers must learn the following skills

- Basic Knowledge of Electricity and Electronics
- Types of sensors and their principle that are required in agriculture
- Types of actuators required to control farm operations
- Information that is required by farmer on environment, soil and plant for improved control
- Knowledge of networking of sensors and actuators
- Internet, artificial intelligence and use of robotics in farm
- Sensors, Ultrasonic Depth, Capacitance Soil Moisture, MPS Matrix Potential, BMP Temp, Humidity, Pressure, AM2320 Temp, Humidity

Conclusion

Remote sensing and GIS are useful in the generation of information for various components of agricultural systems. The satellite data helps in assessment of crop growth and condition, which can then be used to derive the information on yield, area and production. However, the forecasting of crop yield using satellite remote sensing needs historical archives of high-quality statistics, which are not available in all the countries. The hyperspectral data is useful for precision agriculture and soil fertility assessment, but more automated approaches to handle this type of big data are required. In order to enhance the use of satellite data for agricultural monitoring, the coordinated and complementary efforts to develop human and institutional capacity for using the remote sensing technology is required.

Suggested Reading material

Cao, Q., Y. Miao, H. Wang, S. Huang, S. Cheng, R. Khosla and R. Jiang (2013). Non-destructive estimation of rice plant nitrogen status with Crop Circle multispectral active canopy sensor. Field Crops Research 154: 133-144.

Datt B, Apan A, Kelly R (2006) Early detection of exotic pests and diseases in Asian vegetables by imaging spectroscopy. Rural Industries Research and Development Corporation, Australia, RIRDC Publication No 05/170, pp 31

Govender, M.; Dye, P.J.; Weiersbye, I.M.; Witkowski, E.T.F.; Ahmed, F (2009). Review of commonly used remote sensing and ground-based technologies to measure plant water stress. Water SA 35, 741–752.

Jensen, J. R. (2000). Remote Sensing of the Environment: An Earth Resource Perspective. Prentice Hall, New Jersey, 544 p.

Setia R , Lewis M, Marschner P, Raja Segaran R, Summers D and Chittleborough D (2013). Severity of salinity accurately detected and classified on a paddock scale with high resolution multispectral satellite imagery. Land Degradation & Development. 24, 375-384

8 Upscaling Conservation Agriculture and Agriculture Mechanization in Smallholder Systems

Conservation Agriculture (CA) is a combination of tested scientific technologies in agricultural production. It offers a number of benefits such as arresting and reversing the resource degradation, decreasing cultivation costs, making agriculture more resourceful and it's usage as efficient, competitive and sustainable, whilst increasing resilience to climatic variability, and improving livelihood incomes in both India and Africa. The practice of CA in India and other developing countries including West Africa is now increasing, with increasing demand for better conservation and management of natural resources (soil, water and air). But its level of adoption is still very low and the total area of coverage in West Africa and India could be estimated to be less than 2% of their land. Their is a need to think about the problems faced at the implementing level and devise a strategy involving all who are concerned. In many cases, where their is limited success in CA, this is partly because policies are not favorable, and poor technology reach to the farmers, due to mindset about tillage by the majority of farmers. Under such situations, farmers participation on-farm research to evaluate/refine the technology in initial years, followed by large scale demonstrations in subsequent years is needed. Due to the wide range of agro-ecological conditions ranging from deserts, arid zones, semi-arid to sub-humid zones in India and West Africa, it is important for the promotion and development of CA to identify entry points for implementation.

Scaling out CA can benefit from the involvement of a range of catalytic organizations, both from the public and international sectors, as well as from the private sector. In the recent past many efforts have been made by the development agencies to initiate activities at pilot scale that introduced the principles of CA, often through farmer-driven methodologies and extension approaches, such as Farmer Field Schools or Lead Farmers. Such pilot projects have provided the necessary inputs including CA equipment (principally no-till planters, animal drawn rippers and equipment for chemical weed management). The most effective of these tools, the ZT planters, are hardly available in African countries and needed to be imported from other countries. Moreover, farmers and farmer groups that have adopted and understand the benefits of CA for soil improvement and increased resilience to climatic extremes (intense rainfall events and prolonged periods of drought), and subsequently more stable and improved yields, are still remain averse to investments in CA machinery. Agricultural mechanization is a means to increase labour and land productivity, and is but one element in the array of inputs needed for a successful farming enterprise. As with any other input, agricultural mechanization has a supply chain comprising a number of stakeholders. Each of the stakeholders, with the possible exception of some of the services provided by the public sector, is active in the supply chain in order to make a living. This means that their activities must generate a surplus which will recompense them for their time and effort. The roles played by the various stakeholders will be site-specific, and will be very variable. Greater support from stakeholders including policy and decision makers at the local, national and regional levels will facilitate expansion of CA and help farmers to reap more benefits from the technology.
The technical, economic or financial barriers to its adoption exist. The objective for scaling up CA in both Indian and African agriculture, is to contribute to achieving food security in a sustainable fashion, increasing livelihoods' income and conserving the environment. We need to target small scale and medium scale farms, large scale commercial farms, policy and decision makers, private sector stakeholders in agriculture and educational institutions. For the West African

context their is a strong agreement that soil and water conservation, as well as intensification of crop systems along with improving farmer's capacities to engage into adaptive management are part of key pathways, which CA interventions should support. The use of efficient water technologies in semi-arid regions opens significant space for CA practices in rainfed and arid regions of India and West African countries. This chapter lists challenges to the adoption of CA, and aims at providing the basis for upscaling CA, by addressing the strategy and approaches to engage policy makers and other stakeholders (farmers, donors, researchers, extensions and the private sector) in the challenge to move beyond pilot and demonstration plots.

8.1 Challenges to adoption of conservation agriculture

CA is now, considered a route to sustainable agriculture. Although CA is practiced on all the continents where cropping is done, about 180 mha of the world's cropped area is under CA. Despite the several benefits of CA (as listed in chapter 1.7), it has only been practiced globally on about 12 percent of the total cropped area. India now has about 2 million ha of smallholder ZT wheat, but the adoption is relatively slow, (Mottaleb et al. 2016). The double CA system of rice and wheat both under CA has not yet been broadly adopted in India. Eventual wide adoption of ZT direct seeded rice will likely be driven primarily by the increasing costs of labour for hand-transplanting rice seedlings. This is in part because many farmers are still unaware of CA opportunities, training is demanding, and their is a scarcity of trained service providers (SPs) with the right equipments, who plant on a contract basis. The low adoption of CA worldwide challenges the assertion, that CA is a universal technology. In many cases, the problems associated under CA may be a result of less than the recommended CA practices being implemented by farmers. In some farming systems, practicing diverse crop rotations is limited due to following reasons, i.e. market issues, farmer food preferences, the capital and labour required to produce new crops, such as cover crops. While other factors influence farmers adoption of CA practices is the facilitating uptake of specific principles, such as minimum or no soil disturbance, is an important starting point in the use of CA. The low adoption rates of a technology reported to have significant agronomic and economic benefits points to issues with CA. Spread of CA, therefore, will call for scientific research linked with development efforts. In general, uptake of CA technologies has been quite limited in Africa, primarily because of reasons like competing uses for stover/straw as forage, low residue production, and lack of suitable machinery or machine services. CA does not work if the residues are not retained, when suitable equipment is not available (Theirfelder and Wall, 2011). Now mechanization industry is growing throughout the IGP, especially in Eastern India and Bangladesh, but requires further investment and support for its acceleration. Hence the strong interdependence between ZT and mulching becomes an important constraint to the adoption of residue retention practices in Africa and India. The main barriers to the adoption of CA practices are:

i. While the basic principles which form the foundation of CA practices, that is, zero/no tillage and surface managed crop residues are well understood, adoption of these practices under varying farming situations is the key challenge. These challenges relate to development, standardization and adoption of farm machinery for seeding with minimum soil disturbance, developing crop harvesting and management systems. A lack of appropriate smallholder no-tillage planters is one of the principle constraints in adoption of CA (Johansen et al., 2012). Although significant efforts have been made in developing and promoting machinery for ZT seeders (e.g. Happy Seeder in North-West India) for seeding into crop residue, successful adoption will call for accelerated efforts in developing, standardizing and promoting quality machinery aimed at a range of crops and cropping sequences. Residue retention complicates field operations such as planting and weeding, particularly in manual systems (Baudron et al., 2012). Even the most popular animal-drawn CA equipment – chisel-tine rippers – cannot seed in residue-covered soils (Johansen et al., 2012). Further time-saving investments include the acquisition of machinery such as rippers and direct seeders, herbicides, and hired labour. Many studies focusing on CA highlight labour shortages as a constraint to the adoption of CA, particularly when ZT is not complemented by the application of herbicides. Although this situation should in essence stimulate adoption of cost saving Conservation Agriculture technologies, such as reduced tillage systems, and direct seeding; many small scale farmers are not finding equipment and herbicides accessible or affordable. Adoption of CA will remain low in smallholder agriculture in Africa and South Asia, as the technology is not compatible with most of the smallholder farming systems. The lack of subsidies and efficient incentives in a context of high poverty rate in rural areas, does not create favorable environment for CA practices adoption.

ii. The retention of crop residue as a permanent soil cover is difficult due to their multiple uses on smallholder farms, and the current land tenure systems in which arable fields turn into communal grazing areas during the dry season. In addition, the retention of crop residue is perceived by smallholder farmers in Africa to increase termite populations that may subsequently attack crop. In the areas, where crop residues have competing uses such as animal feed, roof thatching and domestic fuel, at least some parts of the stubble should be left in the fields as mulch. Residue mulch in combination with ZT is critical for maximizing and sustaining the beneficial effects of CA. Under rainfed situations, farmers face a scarcity of crop residues due to less biomass production of different crops. This is a major constraint for promotion of CA under rainfed situations. In some regions of Africa, termites accounted for the disappearance of 40–80% of residues during the 6 months of the dry season (Baudron, 2011).

iii. As the land holdings of many smallholder farmers with < 2 ha, localized joint ownership or service provision of low-powered or draught-powered machinery that disturbs the soil as little as possible may be the most realistic method of providing farmers access to mechanized planting, and weed control technologies.

iv. Crop diversification and rotation is not only challenged by the dominance of a few crops, but also by the fact that different soil types in the same farm may differ in their suitability for particular crops (Baudron et al., 2012). The labour requirements for different crops may also vary, potentially limiting the scope for crop rotation in the generally labour-constrained smallholder farms of Africa. Similarly, the practice of intercropping is generally limited to small land areas, or to farmers with small holdings (Baudron et al., 2012).

v. Probably the most important factor in the adoption of sustainable CA based production systems is a change in mindset of farmers, extensionists and researchers away from soil degrading CT operations. It is argued that convincing the farmers that successful cultivation is possible without tillage, is a major hurdle in promoting CA on a large scale. In many cases, it may be difficult to convince the farmers of potential benefits of CA beyond its potential to reduce production costs, mainly by tillage reductions. Lack of knowledge about the potential of CA to agriculture leaders, extension agents and farmers. This implies that the whole range of practices in CA, including planting and harvesting, water and nutrient management, diseases and pest control etc. need to be evolved, evaluated and matched in the context of new systems. Lack of knowledge on how to undertake CA and its benefits is the most common reason for its slow adoption in Africa. Farmers need to acquire the basic knowledge before attempting to try the practices on their own farms.

vi. Weed management is believed by many to be the main constraint to the widespread adoption of CA in Africa. It is frequently noted that the move from plowing to NT or minimum till will increase dependence on herbicides in the first years. However, these weed problems are mainly linked with sub-optimal CA practices, because under CA weed pressure decreases and management improves after the initial two years. The CA adoption in many African countries may be dependent on affordability of herbicides for smallholder farmers.

vii. Essential national policies and regulations as well as international commitments enabling CA practices exists, but their implementation and enforcement in the field remains very weak. Land resources are usually taken for granted, and therefore incentives (including subsidies for improved access to inputs) for better land care programmes and development do not constitute a priority in most African countries. The level of national budget investment in sustainable land management (including CA) is very low (<1% of the country's budget).

viii. CA practices result in resource improvement only gradually, and benefits come about only with time. Indeed, in many situations, benefits in terms of yield increase may not come in the early years of evaluating the impact of conservation agriculture practices. Understanding the dynamics of changes and interactions among physical, chemical and biological processes is basic to developing improved soil-water and nutrient management strategies. Therefore, research in CA must have longer term perspectives.

ix. Adapting strategies for CA systems is highly site specific, yet learning across the sites will be a powerful way in understanding why certain technologies or practices are effective in a set of situations, and not effective in another set. This learning process will accelerate building a knowledge base for sustainable resource management.

x. The level of awareness of policy and decision makers including private sector, on the potential of CA is insufficient. Extension services and other actors' (NGOs) capacities are insufficient in the area of scaling up the success of CA obtained at local levels.

Above factors should be taken into consideration when encouraging farmers to adopt CA.

8.2 Education, Training and Knowledge Management/ Sharing

Adopting CA requires access to and understanding of how to use new equipment, and acceptance of residue mulch on fields. Farmers should be made aware about the business cases, which will help farmers understand their options, the related costs and benefits, and demonstrate to the government how valuable a transition would be, of away from burning of residue will be for citizens. Training of better-off smallholders will generate more adoption and more impact. CA technology is a knowledge intensive with many new aspects and those who must promote it or practice it require training and practical experience. Training and capacity development are one of the core areas for out-scaling of CA. Therefore, their is a need for strengthening of capacity development of whole range of value chain actors, involved in the process of CA technology package (manufactures, operators, farmers, extension agents, civil society, policy planners, etc.). Weak capacities at institutional, community and various stakeholders' levels are hindrances to scaling-up CA in West Africa as well as in India. Capacity development of stakeholders is one of the major pre-requisites for successfully implementing the CA, and mechanization programs. Availability of trained human resources at ground level is one of the major limiting factors in adoption of CA. Consideration of extension approaches such as the 'Lead Farmer Approach', should also be made as a way to mitigate extension shortages at the local level. In the long term, CA should be included in curricula from primary school to university levels, including agricultural colleges. Many capacity-building mechanisms exist, but farmers and service providers still lack the skills and support to use the CA machinery. Rapid increases in awareness and capacity could be achieved through targeted information campaigns, and capacity-building programs that are co-designed by a coalition of partners, who serve the agricultural community.

Public awareness and knowledge can also be created by targeting key policy makers, advisors and engaging governments/decision makers' policy in events related to CA. Inclusion of CA in the curriculum of agricultural universities and vocational training, is an important step to give trainings to the future generations on CA. The state agricultural universities and central institutes can play an important role in imparting the trainings and capacity building. Dedicated training courses for this purpose are needed, to generate a common understanding among the trainees. The training institutions should maintain close links with the field research work and gathered experiences to gain feedback and to make appropriate adjustments to the programme for the reining of future courses which cover both theory and practice.

Since, lack of awareness about CA is one of the serious barriers in uptake of CA technologies (ZT and surface retention of residues), their is an urgent need to plan awareness campaigns to address some of barriers to adoption (lack of knowledge, risk factors). It is recommended raising awareness among farmers, service providers and policy makers, about the merits of the technology through multiple means, including widespread on-farm demonstrations, farmers' fair, field days, exhibitions, traveling seminars, group meetings and other activities. Targeted awareness and capacity-building initiatives will introduce more farmers for CA adoption, and will help ing building public support to avoid residue burning. Use of digital technologies (ICTs), development of documentaries, social media, electronic and print media (e.g.TV and newspaper advertisements) needs to be launched and monitored for their efficacy in terms of implementation and adoption of CA.

Demonstrations of CA technologies are important to catch the interest of other potential supporters. For this reason, it will be desirable to work with innovative and capable farmers, who are prepared to describe and share their experiences with a wider range of people, beyond the farming community. Such demonstrations would need to be clearly visible (e.g. alongside public roads), and offer ease of access to people from e.g. commercial organisations, different branches of government, potential financiers who might assist broader expansion, and other stakeholders. Specifically-arranged study visits to different areas within their own country/regions and among farmers in very different circumstances, can be powerful means of engendering new ideas.

A common practice amongst farmers is to evaluate any farming practice in terms of the total yield only. However, in the initial 1-3 years, CA practices may not increase yields, but save input costs in terms of less fuel usage, better soil health, lesser water consumption etc. As part of the awareness programs, farmers should be made aware of their savings owing to less input costs and input-output price structure. Young farmers could be targeted as potential new adopters of the CA technology approach, as they are generally more interested in trying new technologies and entrepreneurship. Model business plans will provide a platform to new CA machinery service providers, and innovation networks will open new doors for entrepreneurs to find efficient, bottom-up solutions for CA adoption.

8.3 Business Models for upscaling Conservation agriculture technology-custom hiring services

The mechanization of agricultural operations in West Africa and India faces critical challenges in terms of large share of small and marginal farmers, declining land holding sizes, high cost of farm machinery and equipment, undeveloped markets, complex operations and insufficient policy framework. CA requires mechanization, and the necessary equipments may be beyond the reach of the majority of smallholder farmers, and a logical solution to this situation is to provide CA mechanization services through the private sector entrepreneurs. For the successful introduction and up scaling of CA in a country, the availability and accessibility of equipment and machinery for CA is often one of the biggest impediments. Farmers would benefit from receiving trainings of the use of CA. While developing mechanization strategies, all three pillars of sustainability should be considered.

Small holdings do not generate adequate income and inhibit farmers to rent or apply CA technologies. Furthermore, smaller land sizes increase variable costs as the time and distance between serviced lands are enhanced. Poor socio-economic condition may hinder farmers to invest in new climate smart agricultural developments. Farmers consider staff of cooperatives and service providers as peers, from whom they are willing to learn more compared to outsiders.

The hire service will be not be economical when fields are small with long travel distances, unaffordable rental charges, problems of non-payment of charges, inflexible and inefficient public sector administration, lack of operator and mechanic incentives, breakdowns, and the non-sustainability of the subsidies that were required to keep the service running.

With small land holdings, farmers often do not have the necessary capital, either as savings or via access to financial credits, to invest in the expensive farm power and machinery; farmers face difficulty in justifying ownership of any kind of agricultural machinery. Their are several models of equipment usage, e.g. individual ownership of a farmer, collective ownership, and custom hiring services. Promotion of farm mechanization through custom hiring centres (CHCs), private entrepreneurs, farmers organizations can also benefit farmers, especially small and marginal farmers Case studies of Punjab, India show that above' business models can be seen as a mechanism for adoption of CA technologies.. Large scale adoption of laser levelers and combine harvesters in Indian Punjab and adjoining states, is an apt example to understand the importance of cooperative and custom hiring system in machinery adoption and popularization. Financing is one of the major challenges associated with mechanization, as the purchase and maintenance of the necessary equipment constitutes a huge investment, and financial burden for rural enterprises in developing countries, even in the context of alternative mechanization models.

The purchase of machinery by individual farmers is not the only option. Farmers can also pool their resources informally with their neighbours, or formally within the framework of a machinery ring, thus improving their access to loans and machines. Cooperatives and service providers provide access to the latest technologies to farmers in a relatively short distance, in a trustworthy environment without the need of farmers to purchasethe machinery themselves. Another model involves specialist service providers, who not only supply the machinery, but also the entire tillage and other services against payment. The major advantage of such alternative exploitation or ownership models is the CA machines' availability without high investment costs. Lack of skills in the application of CA technologies could be a critical issue with cooperative members. Potential service providers face many constraints, which range from poorly-functioning equipment supply chains and limited financial services to inadequate market demand, for the farmers unaware of opportunities and benefits and equally lacking in finance. With regard to CA, the core question for any prospective service provider must be the extent to which local farmers have been exposed to the ideas and methods that underpin the system. For smallholders in West Africa, use of CA machinery to plough their fields using livestock or manual physical labour, a solution is shared access to machinery via farmer syndication/cooperatives, and/or custom hiring centres (CHCs). The following business models can be adopted for upscaling of the CA machinery.

i. **Individual ownership by the farmers:** This model involves private ownership of machinery by medium and large scale farmers for their use. Many farmers are interested in purchasing a CA machinery themselves, however, the high purchase price of the machinery is a deterrent.

ii. **Medium and large farmers purchasing CA machinery for their own fields and undertaking local custom hiring:** Many medium and large-scale farmers will purchase affordable machines (such as multipurpose 2WTs) who in turn becomes service providers to other smallholder farmers. These farmers have the opportunity to supplement their farm income by the purchase of the CA machinery, for their own use and to help and provide the services in the neighboring fields too. The potential advantage in this model is that the localized nature of the business will allow higher operational efficiencies, through strong local linkages with clients within 15-20 kms from their home base. These farmers can also act as change agents for the uptake of CA technologies, where their business models may be seen as adoption and scaling mechanisms.

iii. **Custom hiring of CA machinery through farmers groups:** Most farmers cannot afford to purchase machinery individually, so shared ownership is one of their few options. In partnership mode, two or more farmers own the business. In collective mode, group may be a formal organization (e.g. farmer association) or an informal association (e.g. self-help group). Farmers may form a local business group where they could purchase multiple numbers of CA machines for the purposes of establishing a CHC business. There are advantages and disadvantages to each form of ownership and careful consideration is required when deciding the best form of business organization. For example, a partnership between two farmers has the advantage of reduced costs when buying a tractor and equipment; on the other hand, the farmers have their own requirements regarding personal use and, consequently, limitations with regard to availability for hire services. However, many of the farmers are discouraged in such ownership models, due to the risk of conflict and arguments arising. Typically, service providers comprise of larger farmers who owned their own tractors and engaged in CHC business operations as a side business. Such farmers were more likely to have higher levels of education and wider social networks, and had greater capacity to provide services at a sizeable scale.

iv. **Custom hiring of CA machinery through agricultural cooperative societies:** The primary agricultural cooperative societies (PACS) have the advantage of buying the agricultural implements at higher subsidy (with direct benefit transfer) from government institutions, compared to private CHCs and have strong linkages with farmer members. These societies also have the advantage of availability of tractors, which are used for other operations. Cooperative agricultural societies are well placed to provide custom hiring service at competitive rates (either with or without tractor and driver). Group members coordinate their farming tasks, and exchange skills and best practices. Cooperatives concentrate on tractors, plows and trailers and processing equipment. The cooperative system is based on voluntary membership of small farmer groups that wish to invest in machinery. Each individual farmer is free to join a cooperative society, and has a right to participate in the decision making process. Each member is obliged to contribute financially to the cooperative; shares are proportionate to the area of land on which a farmer wishes to use the machinery. Thus membership and machinery access become feasible for small-scale farmers, while at the same time also offering viable opportunities for medium-scale farmers. The custom hiring of the agricultural implements through PACS can be a financially viable option for farmers. These institutions have experience with leasing and renting out equipments, and strong linkages with the farmers. However, it is important, that a uniform rental rate should be fixed for renting out the implements. Moreover, financial responsibility boosts involvement, participation, and a sense of ownership on the part of producers. Each farmer contributes to the costs related to the use of the material proportional to his/her use. Good scheduling is essential, as farmers in the same region tend to demand land preparation and harvesting services simultaneously. Developing cooperatives is however, very challenging and their have been many failures. Farmers are more open to receiving and getting knowledge from people from their own community.

v. **Custom hiring service by private entrepreneurs:** The larger and more complex CA equipment is expensive and users may have to hire it. Their is an opportunity to develop a local custom hire service industry by providing equipment, and training on machine maintenance and business skills. Concept of CHCs holds good potential provided their is an integration of all the operations viz. provision of agri-inputs like seeds, fertilizers, implements etc. through partnerships with various companies. Delivery of machinery services, particularly large and expensive machinery such as combine harvesters, laser leveler, etc., through private contractors, entrepreneurs is common in NW India. This model shows considerable potential to deliver the combination of extension and machinery. They may be encouraged to acquire CA machinery also, it may lead to a successful business model for large-scale adoption of CA. A CHC is a business that provides services for different field operations, post-harvest operations, processing, transportation and marketing. To run a hire service as a profit business enterprise, it is important to develop good relations with customers and clients, forging business partnerships (who to join up with), efficiently managing the business, offering different services, and make profits. The advantages of this model are the economies of scale, which may be able to cover large areas without the need to upgrade tractor or operational skills. This model shows considerable potential to deliver the combination of extension and machinery. The set of CHC business models should be tailored to local contexts and describe uber-type, rental, and manufacturer service models. These model plans would specify annual costs and potential profits, necessary upfront costs, return on investment, options for funding and training, marketing outlets, and a step-by-step description of how to apply for funding, receive necessary trainings, and provide services using the specific model. Entrepreneurial support would be useful, but this would require identifying institutional and financial support and launching a support platform.

Custom Hiring Centres (CHCs)

Custom hiring enables farmers to rent the appropriate equipment, often along with someone to operate it, for a defined period of time only, thus only paying for the services of the machine without having to own it. Custom hiring has a major role in agricultural mechanization for the following reasons: (i). Small landholdings, (ii). Low purchasing capacity, (iii) Low technical capability, and (iv) Economy in renting of agricultural machinery. Majority of the farmers in India and Africa fall under the small and marginal category, is making individual ownership of agricultural machinery progressively uneconomical. Therefore, necessary steps to promote the agro-service providers through farmers' cooperatives/custom-hiring centres for the small and marginal farmers could reap the benefits of farm mechanization. For small and marginal category, purchase of farm equipment is a significant investment for them. Reasonable financing norms are a must for making farm equipment, and machineries available at affordable price and enhance farm mechanization. Commercial banks and financial institutions need to develop hassle free loan facility and disbursement process for tractors, and all other types of farm machinery on individual ownership basis or custom hiring centres. Custom hiring envisages promoting establishment of farm machinery banks for hiring by way of providing financial assistance to private entrepreneurs and farmers' co-operatives since the prohibitive cost of CA equipments, renders it difficult for individual ownership. The Custom hiring model holds the potential to be the best way to introduce capital intensive, high quality and efficient farm mechanization to the small farming structures prevalent in India as well as West Africa. Custom hiring through private entrepreneurs or co-operatives will help to increase annual use of the equipment thereby making them viable. The lack of custom hiring opportunities will lead to underutilization of the costly machines. The CHCs can offer farm equipment and machineries on rental basis to small and marginal farmers who cannot afford to purchase high end agricultural machineries and equipment. Concept of custom hiring holds good potential, provided their is an integration of all the operations viz. provision of agriculture inputs like seeds, fertilizers, implements right from hand weeders to pesticide/ weedicide spray pumps, to seed drillers and to the harvesters. The CHCs can bring the t additional income to custom operators and give access to mechanization for all groups of farmers, irrespective of the size of their holdings. Agencies like Krishi Vigyan Kendras (KVKs) in India and extension wings of universities are required to play a very key role in sensitizing the farmers on Custom Hiring adoption. CHCs need to be well-equipped with appropriate CA equipments and will usually benefit from specific trainings on the technical aspects of CA machinery operations, and on the business skills needed to run a profitable venture. The technical skills to be reinforced include: equipment selection, calibration of planters, seeders and sprayers, field operation, maintenance and repair. Business skills needed include: market research and feasibility studies, business planning, calculation of operational costs, partial budgets, break-even points and cash flows. The case is made for local manufacture to reduce the costs of machinery acquisition and to encourage local adaptation. Start-up costs are discussed together with the options of obtaining finance. The hiring services for machinery would require good quality rural road network and large agro-ecological areas, and generally non-fragmented lands, which presently is typically not the case in most African countries and Indian regions. The continuous declining farm sizes is a structural bottleneck in farmers' capacity to invest in agriculture, and is considered a barrier for establishing CHCs, selling CA services at large scale.

Key Objectives of Custom Hiring:

1. To make available various farm machinery/ equipments for different operations, to small and marginal farmers;
2. To offset the adverse economies of scale, due to high cost of individual ownership;

3. To improve mechanization in places with low farm power availability;
4. To expand mechanized activities during cropping seasons in large areas especially in small and marginal holdings;
5. To involve manufacturers/agricultural extension centres in operations and maintenance of machines in the CHCs; and
6. To introduce improved/newly modified and developed CA implements and machines in crop production.

Managing a Custom hire Service Business

Managing the operations of a hire service business involves planning, organizing, leading and controlling the tasks and activities required to run the business and its services, and offering services in a sustainable way. A wide range of operations should be covered by machinery hire services. In addition to crop operations such as tillage, planting, and spraying, other hire services such as seeding, spraying, threshing, shelling, and transportation. Similarly, it is important to note that hire services are not only limited to motorized operations, but also to operations where the source of power is animal draught for smallholder farmers in West Africa. The correct and appropriate selection of a power source and equipment determine costs and significantly affect the profitability of a hire service. For successful operations of the business, hire service providers need strong linkages with machinery and equipment suppliers, spare parts dealers, fuel traders, financial organizations and, of course, their customers. Relations and links to a range of stakeholders will ensure that high quality services are delivered effectively and efficiently to the satisfaction of their customers. Good relations with suppliers and customers contribute to profitability. Service providers offering maintenance and repair services are fundamental for keeping a hire service in business. Successful custom hire service providers for CA machinery should focus on securing profits, while being aware of the long-term negative effect of unsustainable land use.

First step to decide what implements the hire service needs, for implementing CA. Improved performance – in terms of productivity, profitability and efficiency – results in cost savings in both resource use and customer services. Appropriate maintenance of machinery over time ensures that a tractor runs at maximum efficiency, reducing costs and increasing productivity. Customer satisfaction is vital to ensure a profitable business. Proper scheduling and timing result in better precision and, consequently, a reduction in waste.

Financial management includes generating profit for the business, obtaining funds, ordering machinery and equipment to the best advantage, keeping assets in good working order, ensuring adequate cash flow for ongoing activities, and in the long term, achieving business growth. The financial management will cover the following four activities: (i) Assessing the profitability of the business; (ii) Calculating hire charge rates; (iii) Preparing a business plan; and (iv) Risk assessment. A loan appraisal is designed to ascertain whether the hire service is able to cover the interest rates and respect the payback period. Setting of hire charges is crucial, during the selection process, to estimate the purchase and operation costs involved to obtain an indication of how much money the hire service needs to keep operations going. Total costs can be broken down into fixed and variable costs. Fixed costs are those incurred whether or not work is carried out; they do not usually change over time. Fixed costs include depreciation (loss in value over time), interest on investment for machinery purchase, taxes and insurance. The more a machine is used, the lower the unit cost of operation (per hour or hectare). Variable costs depend on the amount of work done. They include fuel, lubricants and repair costs, and vary according to how much the machinery is used, and the type of operations performed. This is applicable also to draught animals. Operator costs may be fixed or variable, depending on whether the operator is a full-time employee (paid whether operating machinery or not) or someone employed only for actual work with the equipment. The greater the machine capacity, the lower the operator costs per unit of work carried out (hour or unit of area). In the case of a full-time operator, the more work done, the lower the cost per unit. In order to know how much to charge for a particular field operation, it is necessary to understand how much it costs to own and operate equipment on an hourly basis, and all other costs involved in offering hire services. It is then possible to set hiring charges.

Both financial and economic evaluation is important for the viability of CHCs. Financial evaluation of business enterprise takes care of direct costs involved in purchase of machinery, and direct monetary benefit of using CA machinery. The economic evaluation analysis considers the both direct and indirect costs and direct economic values for all relevant inputs and outputs. Direct economic values for all relevant inputs and outputs. Health costs (human and animal), traffic hazards, environmental degradation etc. are indirect costs, whereas no burning leads to environment improvement, it is indirect benefits. Another important calculation for someone starting up a business is the break-even point, which means calculating the minimum hours of paid contract work, a hire service provider must do to cover his costs and make some profits, or in other words, stay in business. The prospective service provider needs to know the estimated annual costs of owning and operating CA equipment, and the possible income that he can generate from the hire charges. Then he can work out the overall effect of starting this business with his future income by completing a partial budget. A partial budget is set out, in a way to help someone decide if a planned change in the business enterprises is worthwhile. If total income is greater than total investment cost, the farmer should increase his profits as a result of the change. Otherwise, he will have less profit. This type of calculation is particularly important, if the farmer intends to maintain his farming operations in addition to operating a hire service. The government's subsidy is a driver enabling farmers, to buy or lease CA technologies rather than the cooperative itself. Farmers' gaps in knowledge and skills are well addressed by cooperatives and service providers.

Machine field capacity and efficiency: The power of the tractor's engine, as well as the tractor's weight determine its performance. Knowing the work capacity of a particular machine or tractor/ implement combination, is essential in determining its field capacity and to estimate its revenue earning potential. The field capacity of a farm machine is measured in ha/h. It is used to calculate the total number of tractors, implements and machines needed, as well as the operators required, along with the total number of hectares to be covered. Field capacities are also required for scheduling field operations on a daily, monthly and yearly basis. As an example, let us take a tractor-mounted direct planter of 3 m working width travelling at 5 km/h.

Field capacity = Speed (5 km/h) × width (3 m)/10 =1.5 ha/h

Field efficiency is the actual rate of work achieved, divided by the theoretical maximum rate of work (field capacity). It's value is determined by the actual time the machine works productively. Small, irregularly-shaped fields lead to low machine field efficiency because the machine spends a lot of time turning and thus not working productively. Actual field efficiencies achieved by a hire service, however, depend on many factors, and maximizing efficiency must always be at the forefront of management thinking. Taking the example of the direct planter above and assuming a field efficiency of 65%, the actual work-rate is given by:

Actual work–rate = Field capacity (1.5) × efficiency (65%) =0.975 ha/h

Overall machine efficiency is of critical importance for the profitability of a service provision business, and needs to be understood by service provision managers. It is made up of four components: (i) field efficiency as explained above; (ii) non-productive travel time; (iii) down-time caused by lack of work or bad weather; and (iv) down-time caused by service or repairs. Taking all of these factors into consideration, will give a realistic estimate of the amount of work that can be expected of a machine in any given situation. To work out the annual costs of simply owning the machinery, i.e. the fixed costs. The farmer will need to estimate how many hours of work he expects to be able to do in a season. The total variable costs would double as a result of the extra hours worked, but the rate per hour would remain the same, provided the farmer continued to do all of the work himself. Therefore, the overall cost of the machinery per hour would reduce. The CHC will cover the basic cost of planting, of course, he will not wish to merely cover his costs, but to make a profit, as well. Therefore, he might charge more for the machinery use/operations, which is a mark-up of just over 15%.

8.4 Role of Private Sector in upscaling CA

There are generally four main groups or levels of interested parties in the private sector: e.g. farmers, retailers or wholesalers, manufacturers, and importers. Each of these groups is comprised of small to medium businesses. The linkages between these fours is of the greatest importance to the successful and sustainable development of the sub-sector. A basic, fundamental requirement is that the "businesses" in each of these groups must be profitable. If farmers are not making money, they will not be able to adopt CA; if retailers cannot sell items at profit, then they will not stock them and if manufacturers are not fabricating tools and machines at a price, that can be afforded by the farmer, then their business is unsustainable. This may appear to be a simple observation, but the absence of a thriving agricultural machine and tool manufacturing, importing, and retailing sub-sector can often be traced to the lack of profitability in one of these groups. A major development goal must be the creation of the linkages between each group, and the addressing of issues and sorting it, which affect the profitability of one or more of these groups. The private sector needs to be encouraged and empowered to acquire (import initially) and service new equipment. Development bank and donors could help governments, and private sector partners to ensure sustainability through profits. Across the spectrum of introduction of CA into smallholder systems globally, it is apparent that in addition to the poor availability of appropriate equipment, e.g. no-till planters, herbicide sprayers, land levellers (for irrigated systems), mowers to enable planting into high stubble, etc., rather subtle and detailed management practices also determine success or failure.

Local leaders are considered essential in providing assistance (and guidance) to other farmers in the adoption of the CA machinery. It is not always possible to visit the agricultural department and other extension agencies (e.g. KVKs in India), and so sharing information between other farmers can be highly beneficial. Good local farmer leadership is considered to be an important asset within local village communities. Local farmer leaders can also provide knowledge to other farmer's of the new practices, and can assist the fellow farmers in introduction, adaptation and handholding support for the new change (and help in reforming outdated practices, such as excessive cultivation).

For increasing CA adoption, short-term, targeted financial incentives for farmers, particularly for small scale/ poor farmers, manufacturers and service providers can help increase both supply and demand of CA machinery, to overcome financial risks associated with adopting new technologies. Short-term incentives may motivate risk averse farmers, who are uncertain about the benefits of CA to try CA machinery. The CA machineries (e.g. Happy Seeder) are found useful for CA practices but are costly, and thus are more suitable for rich and medium to large farmers groups. Reaching to large number of farmers through this technology will require production of large number of CA machinery each year. Their should be a provision offering purchase guarantees, which would allow the manufacturers to produce new machines at lower risk, and in time. Concurrent with manufacturing supply efforts, service supply mechanisms also need to expand. In addition to direct purchase subsidies from the government, their is an opportunity to create low or interest free loans for the machinery purchase. Simultaneously the government needs to design easier financing schemes for such farmers. The quality control and the availability of machinery at the local level with after-sale services and spare parts is still an issue.

First of all, manufacturers should carry out market studies to find out the farming practices of the farmers. Then the facility for thorough testing of equipment should be made before commercial production. Manufacturers need to be willing and prepared to incorporate user feedback into the next generation design. Their should be the provision of technical training for manufacturers, operators, dealers and extension staff. Manufacturers and hire service providers, in addition, often require training in business skills and business diversification. Their is a need for support for hire service providers. In order for service providers to make their living, they may be obliged to offer these traditional services in order to sustain their business. Hence, the introduction of CA equipment may have to proceed in steps and their will probably be gradual shift as awareness of the CA concept and equipment will develop over time.

8.5. Government policy support for scaling CA and agricultural mechanization

Policy support is increasingly important in harnessing the potential of CA systems. Policy barriers that constrained adoption of CA technologies includes issues such as farmers' financial capacity, short timeframes for economical use of the technology, a lack of available farmer training resources, and the non-enforcement of crop residue burning bans lowered the probability of adoption. For successful adoption of CA, their is the need to provide credit to farmers, to buy the equipment, machinery, and inputs through banks and credit agencies at reasonable interest rates. At the same time government needs to provide the subsidy for the purchase of such equipment by farmers. This will result in a considerable increase in area under CA. The "subsidy" could be justified as payment for environmental services, considering the reduced impact on the environment from CA compared to CT based farming. But even with adequate capital, farmers in most countries would not be able to find suitable equipment.

Success stories and technical discussions generated by the growing spread of CA technology, as told by farmers and others, will make government department heads, policy-makers, institutional leaders and others aware of benefits, and of the desirability of backing the initiatives. It is important that policy makers come to a better understanding of the implications of CA. This makes it easier for them to justify supportive policies, which in the end are beneficial not only for the farming community but for everyone, and hence for the policy makers and their constituency. Engaging governments/decision makers' policy is important in events related to CA. Governments should involve and integrate the private sector, academia and researchers in their respective domains of competency related to CA.

In African countries most of the available implements and equipment are imported. African farmers need smaller versions of these machines which needs policy support for manufacturing at the local level. Indigenization of many specialized machineries by the private players which are otherwise imported thereby bringing down the cost. To address this problem of unavailability of CA machinery in the country, the market needs to be stimulated, import taxes for equipment and raw material need to be adjusted to facilitate the import, and eventually national manufacturing of CA equipment. As long as no national producer of equipment is servicing the farmers, existing suppliers from other countries need to be proactively brought into the country, including facilitating the building up of dealership and service networks. In this regard, their is a need for local manufactures and equipment suppliers to provide support in supplying seeders and other equipment that would normally not be available in rural outlets. In Africa, by reducing the overall demand for farm power, the change to CA is not necessarily a threat to the agricultural machinery industry, because it could facilitate the opening up of new markets, which so far have been completely left out of farm mechanization.

To enhance uptake of CA technologies, certain policies concerning pricing, incentives, research, agricultural education, funding etc. have to be made. For example, efficient use of water will not occur, if farmers are given it free. This whole issue of policy is complex, since their is a need to balance the needed encouragement of farmers to produce more food at lower prices without unduly degrading the environment and the resource base, while still providing cheap food for the urban and rural poor. Their is a need for the new implements to experiment with the CA technologies; more funds are needed for refinement and development of farm equipment to promote CA and precision agriculture. A better policy would make credit more easily available although repayment schedules must be met. Government policy will determine the interest of individual farmer in owing the machine. Policy changes are needed to affect adoption support arrangements (e.g. subsidised purchasing support arrangements for farmers) to address the constraints in the upscaling CA. Government subsidy for the purchase of machinery is seen as a positive incentive (to compensate the high purchase price. The financial condition of the farmers, especially of the small landholders, is very poor and they cannot afford expensive agricultural implements. Providing a 50% subsidy is considered a very strong incentive for farmers wishing to purchase such equipment. Other areas that government has an immense role to play include providing R&D on locally appropriate and adaptable machinery (such as tractors suitable for small-scale farms, and multifunctional tractors), and providing skill development and vocational and technical training on machinery use and repairs. Locally manufactured implements in India, such as seeders and shellers are affordable and would guarantee quick returns in the short to medium term.

Removing other subsidies such as fertilizer and electricity subsidies, will increase adoption of CA machinery; especially when subsidy funds were also targeted at increased awareness and demonstrations in the field over purchase supports. Increase in access to custom-hire service centres (CHCs) networks by smallholders must be achieved through targeted policy interventions (e.g. increased awareness and support until scale is achieved across communities to provide economies of operation and adoption). To achieve this effectively, current development policies will need to be analysed. This will include laws, rules and regulations that reflect those policies, and particularly those which have an impact on agricultural mechanization. Policy support is crucial for the rapid development of the CA machinery, including provision of adequate research funding for the development of new machinery for the implementation of CA. For smallholders, limited resources and farm size, purchase of large machinery (built locally or imported), is a constraint. A facilitating government policy environment can be an important determinant of for accelerated spread of CA. Most policies to support CA adoption and spread must be enabling and flexible, rather than unitary and prescriptive. Ministry of Agriculture & Farmer Welfare, Government of India prepared a 'National Policy for 'Management of Crop Residue' to reduce the burning of rice residue in 2014 (http://agricoop.nic.in/sites/default/files/NPMCR_1.pdf).

This policy is now encouraging adoption and CA and thereby reducing the burning incidence. Their are several Indian Government schemes related to soil health, water saving, adapting to climate risks, reducing environmental footprints, doubling farmers' income, food security, etc., wherein promotion of CA technology package can contribute substantially.

CA in West African countries is not yet well integrated in government development agendas and policies. The implementation of CA within the mainstream agriculture development and extension services will have important positive consequences for up-scaling of CA practices. One of the important activities to put in place for the promotion and development of CA is the mainstreaming of this concept in the agricultural, environmental and socio-economical strategies, and policies of countries. It is important to assist in the formulation and/or mainstreaming and implementation of proper policy for scaling-up CA practices.

Within this context, the mainstreaming of CA into policy and practice is yet much focused on productivity and adaptive capacity, with lesser concern for climate change mitigation. Increasing farmers' investment involves working with the better performing farmers to evaluate the benefits and trade-offs (e.g. risks) from alternative investments given a limited availability of resources such as fertilizers, herbicides, stubble from previous crops. Gradually incorporating more CA component technologies might be an option for this group of farmers. This approach is likely to provide significant benefits to approximately 60-70% of the farming population across Africa.

To strengthen CHCs and small to medium enterprises (SMEs) as change agents for CA, policy makers should reconsider current subsidy regime and ensure flexible and targeted (financial) incentives. Their is a need to study and replicate successful business models along with incentivization and policy support for the adoption, capacity building and skill enhancement, development and promotion of farm mechanization technologies.

8.6 Engaging and empowering women and youth in scaling CA and agriculture mechanization

Farnworth et al. (2016) argued, that despite wide-ranging, in-depth studies over many years, only a few CA studies consider gender and gender relations as a potential explanatory factor for (low) adoption rates. Implementation of CA will inevitably involve a reallocation of men's and women's resources, as well as having an impact upon their ability to realize their gender interests. CA interventions have implications for labour requirements and labour allocation, investment decisions with respect to mechanization and herbicide use, crop choice, and residue management. The attention to gender in CA is important, due to the increasing interest in CA as a means of adapting to climate change. Whilst capital and labour requirements are central to the suitability of CA for smallholder farmers, surprisingly little attention has been paid to the ability of women farmers, within male-headed households to meet such requirements in African countries. The costs and benefits of CA adoption to women themselves – in terms of income, labour deployment, contributions to food and nutrition security, relative decision-making power at household and community level, potential integration of their into value chains and extension networks – remain largely unknown. While CA is practised in several African contexts, little is known about its interaction with gender. It is important to address gender in CA for equity, rights, and inclusiveness (SDGs), and economic cost in CA.

Adoption of CA had both positive and negative impacts on men and women farmers' labour demands. Positive impacts of CA on labour demands derived from the practice of crop residue retention, which eliminated the need for clearing of pre-tilling land and tended to reduce the workload for women and children (Nyanga et al., 2012). Integrating CA practices inevitably effect on-farm gender relations, notably resource allocation, as well as having an impact upon the ability of women and men to realize their gender interests. Basin-based CA, the most common manual CA system in Africa, is predominantly practised by women. Thus, CA enabled them to spread the workload over a long period of time, and still have their land ready in good time for early planting (Farnworth et al., 2016; Hove & Gweme, 2018). When land preparation and planting isdone using rippers and direct seeders, poor men and women may loose employment opportunities (Beuchelt and Badstue, 2013). Women and men typically take on distinctive roles and responsibilities in agricultural production systems, with tasks frequently being both sex-sequential and sex-segregated (FAO, 2011; O'Sullivan et al., 2014). Research shows that CA shifts much of the responsibility of land preparation from men to women and children, increasing women's and children's workloads while decreasing the need for men's labour (Nyanga et al., 2012).

In most African countries, women are almost exclusively responsible for childcare and household tasks and caring roles. These can be very time-consuming. Although gender roles and responsibilities are undergoing significant change in different parts of the continent, African farming systems and the wider policy environment generally remain strongly gendered. The ability of women to take decisions as to whether to invest in new technologies, such as CA depends on many factors. These include their entitlements within the frequently gender differentiated resource base of African farming systems, gender differences in access to information and the ability to act upon it, gender differences in participation in community and marketing networks, women's marital status, and the complex arena of intra-household decision-making. Their are indications that women are using the opportunities presented by CA to manage the intensity and timing of their labour contributions on their own, and on male managed plots. In general, herbicide use in CA farming results in both women and children reporting more opportunities to rest, and engage in other economic activities and to go to school, respectively (Farnworth et al., 2016; Nyanga et al., 2012). Use of herbicides in CA also increased incomes and employment opportunities for men who dominated the herbicide spraying business (Nyanga et al., 2012). However, CA practices using herbicides, may result in poorer households losing labour opportunities, and may therefore become a mechanism of advanced social differentiation (Andersson & D'Souza, 2014; Ngwira et al., 2014). Focusing on the opportunities and constraints offered by CA to young men and women farmers, and also to hired labour need further research in West African countries. Finally, given that the benefits of CA appear to improve with increasing investment, particularly in mechanization and herbicides, it is essential to establish the overall capacity of smallholders to invest, and specifically by gender.

Compared to men, and due largely to gendered barriers, including lack of access to land; machinery; inputs; extension services; and credit facilities, women farmers adopted CA less and disadopted it more. CA will increase women's incomes, labour involvement, household food security, as well as risks for land and crop dispossession by men, when farming becomes lucrative. It will also increase workloads, employment opportunities and health risks for women. CA positively altered gender relations, boosting women's participation in agricultural decision-making at the household level. Currently, much of the existing research and evidence on CA and gender in the region is fragmented, fails to provide a consolidated perspective of key issues and lessons, and remains largely irrelevant to the knowledge needs of funders, decision-makers, and key agricultural groups in SSA (Giller et al., 2009).

The evidence on CA in relation to incomes and food security for men and women is not consistent. Women participating in a CA project in Zimbabwe reported increased grain yields, enhanced household food security, ability to eat three meals a day, greater dietary diversity, and enough food to last them until the next harvest season (Hove & Gweme, 2018). However, increased productivity and incomes due to CA could also lead to the disempowerment and dispossession of women. CA discouraged intercropping of maize with other traditional foods, thus reducing women's ability to guarantee household access to food variety in Zambia (Nyanga et al., 2012). A study on factors affecting the adoption and intensity of CA practice in Masvingo District, Zimbabwe, found that, in almost half of the households that practised CA, women were the crop managers or co-managers, contrary to the widely held perception that women farmers in SSA only provide labour and had little role in management decisions (Kunzekweguta et al., 2017). The ability of women to engage in decision making in the contexts of CA is affected by their marital status; access, control and ownership of productive resources, including land; level of awareness of CA; sense of agency and intra-household power relations (Farnworth et al., 2016). CA has the potential to increase household food security, positively transform household-level gender relations in favour of women, lead to increased incomes for women and enhances the women's decision-making capacities. Considering the gender disparities that are inherent in CA, mainstreaming gender concerns as highlighted by Nkandu (2012) and Mukuka (2013) could improve women's and men's participation in CA activities. Custom Hiring Service facility for farm machinery to farmers will provide job opportunities to unemployed agricultural graduates. Research and extension services can help CHCs in the acquisition of new knowledge and skills, which they can in turn share with their customers. Promotion of the formation of farm cooperatives and farmers groups which eventually increases the scope of use of bigger farm machinery and results in minimum wastage of resources.

General tradition of harvesting and pod picking in mungbean crop in Eastern India, is a job generally assigned to woman folks in the community (Fig. 8.1). Thus, the introduction of the pulse crop in CA based rice-wheat system not only breaks the monotony of the cereal production system, but also improves house hold food security, and provide local employment to the extent of close to 75-man days/year.

Figure 8.1. Women hired labourers picking mung bean in Eastern Indo-Gangetic Plains of India (Photo R.K. Jat)

8.7 Research and Development

CA is solution to several mega challenges being faced in farming such as climate change, water scarcity, agricultural pollution, soil health, farm profitability, human health, etc. As such CA contributes to at least 8 Sustainable Development Goals (SDGs), while ensuring future food security on a sustainable basis and hence, while promoting and prioritizing investments, CA needs to be looked from the perspective of these mega challenges rather than mere cost cutting and labour saving technological options.

Concerted efforts need to be made in research and development to enhance precision in farm equipment. CA as an upcoming paradigm for raising crops will require an innovative system perspective to deal with diverse, flexible and context specific needs of technologies and their management. CA R&D (Research and Development) will call for several innovative features to address the challenges.

- Conduct research to validate and further modify the farm equipment and machinery for CA suited to local requirements considering soil, climate, cropping systems as well as socio-economic conditions. Intensify R&D on developing sensors, monitors for CA equipment by suitable modification wherever required.
- Develop equipment to cope up with the power requirements, safety, etc. Develop gender neutral, efficient, robust and easy to operate precision farm equipment and machinery.
- Their is an urgent need to develop the long-term CA research platforms, as sites of learning as well as new scientific insights and evidence generations, the on-farm research-cum-demonstration with farmers participation is the key for its upscaling and promotion on large areas. Innovation platforms and networks can help in rapid change in CA adoption at large scales. The innovation networks can support a range of opportunities, from informal farmer-to-farmer meetings that allow alternative technology demonstrations, to competitions that award prize money to support innovative new ideas. The innovation platforms should consider the full supply chain and farmers, service providers, manufacturers, buyers and others to identify challenges and problem solve together. Such platforms can be used for farmer-to-farmer learning, and to encourage social changes to remove the barriers to bring the positive change in socio-economic condition. Krishi Vigyan Kendras (KVKs) established in India can be such platforms. These centers provide farmer training, demonstrate new technologies and support information and technology diffusion.
- Tailoring efficient genotypes for CA is important as those bred for conventional agriculture may not do well. Crop cultivars specific to CA having quick seedling emergence characteristic need to be developed and evaluated. Investigate genotype x environment x management interactions under CA.
- Scale appropriate machinery for CA based management under diversity of cropping systems and production ecologies is one of the critical factors for success or failure of CA and hence CA mechanization priorities need to be defined and strengthened in the regions having week manufacturing capacity. Special emphasis on establishing CA mechanization hubs in rainfed ecologies and eastern India should be made.
- Establishment of testing facilities for farm equipment / machinery is very important to test critical components and equipment for quality, and performance to ensure that the observed data falls within the specified range of accuracy.
- Irrigation water and nutrient management research under CA should consider issues such as scheduling irrigation, nutrient recycling through crop residues & soil moisture conservation through residue mulch, innovative approaches such as drip irrigation & fertigation, deep placement of fertilizers.
- Soil biology (community structure of microbes, microbial dynamics and microbial mediated processes), and weed and pest (including insects, pathogens) dynamics under CA need to be studied.
- Database development and research activities for scaling up CA practices needs to be undertaken. Their is an urgent need to ‘establish a formal technical working group on CA involving key researchers from different national and international agencies (e.g. BISA, CIMMYT, FAO) and other relevant organizations with very precisely defined roles and responsibility to promote CA through (i) mapping CA research and development initiatives, (ii) define recommendation domains of CA based management systems, (iii) Identify research

gaps and address all pertinent questions and concerns related to CA, (iv) act as CA knowledge repository and sharing center, (v) serve as catalyzing capacity development of stakeholders, (vi) develop policy guidelines and advisories based on science-driven CA research for out scaling CA, (vii) develop proposals and raise funding on CA research and development, (viii) act as facilitator of south-south collaboration, (ix) Framework established for tracking adoption and social impact of CA, and (x) Monitoring and evaluation of CA adoption in India.

Focusing on the opportunities and constraints offered by CA to young men and women farmers, and also to hired labour need further research. Finally, given that the benefits of CA appear to improve with increasing investment, particularly in mechanization and herbicides, it is essential to establish the overall capacity of smallholders to invest, and specifically by gender.

References

Andersson, A. and D'Souza, S. (2014). From adoption claims to understanding farmers and contexts: A literature review of Conservation Agriculture (CA) adoption among smallholder farmers in southern Africa Jens. Agric. Ecosys Enviro. 187, 116-132.

Baudron, F., Sims, B., Justice, S., Kahan, D.G., Rose, R., Mkomwa, S., Kaumbutho, P., Sariah, J., Nazare, R., Moges, G., et al. (2015). Re-examining appropriate mechanization in Africa: Two-wheel tractors, conservation agriculture, and private sector involvement. Food Secur. 7, 889–904.

Baudron, F., Tittonell, P., Corbeels, M., Letourmy, P. and Giller, K. E. (2011). Comparative performance of conservation agriculture and current smallholder farming practices in semi-arid Zimbabwe. Field Crops Res.132, 117–128.

Beuchelt, T.D. and Badstue, L. (2013) Gender, nutrition- and climate-smart food production: Opportunities and trade-offs. Food Sec. 5, 709–721.

Farnworth, C. R., Baudron, F., Andersson, J. A., Misiko, M., Baudron, F., Badstue, L., and Stirling, C. M. (2016). Gender and Conservation Agriculture in Eastern and Southern Africa: Towards a Research Agenda. Inter. J. Agric. Sustain. 14, 142–165.

FAO. (2011). The state of food and agriculture: Women in agriculture. Food and Agriculture Organization, Rome, Italy.

Giller, K. E., Witter, E., Corbeels, M. and Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Res. 114, 23-34.

Hove, M. and Gweme, T. (2018). Women's food security and conservation farming in Zaka District-Zimbabwe. J. Arid Environ. 149, 18–29.

Mottaleb, K.A., Krupnik, T.J. and Erenstein, O. (2016). Factors associated with small-scale agricultural machinery adoption in Bangladesh: census findings. J. of Rural Studies 46, 155–68.

Johansen, C., Haque, M.E., Bell, R.W., Thierfelder, C. and Esdaile, R.J. (2012). Conservation agriculture for small holder rainfed farming: Opportunities and constraints of new mechanized seeding systems. Field Crops Res. 132, 18–32.

Kunzekweguta, M., Rich, K. M., and Lyne, M. C. (2017). Factors affecting adoption and intensity of conservation agriculture techniques applied by smallholders in Masvingo district, Zimbabwe. Agrekon, 56, 330–346.

Nyanga, P. H., Johnsen, F. H., and Kalinda, T. H. (2012). Gendered impacts of conservation agriculture and paradox of herbicide use among smallholder farmers. Int. J. Tech. Dev. Studies, 3, 1–24.

O'Sullivan, M., Rao, A., Raka, B., Kajal, G. and Margaux, V. (2014). Levelling the field: Improving opportunities for women farmers in Africa. Vol. 1 of levelling the field: Improving opportunities for women farmers in Africa. Washington, DC: World Bank Group.

Thierfelder, C. and Wall, P. C. (2011). Reducing the risk of crop failure for smallholder farmers in africa through the adoption of conservation agriculture. In: Bationo A., Waswa B., Okeyo J., Maina F., Kihara J. (eds) Innovations as key to the Green Revolution in Africa. Springer, Dordrecht

Suggested background reading:

Brown, B., Nuberg, I. and Llewellyn, R. (2017). Negative evaluation of conservation agriculture: perspectives from African smallholder farmers. Int. J. Agric. Sustain. 15, 467–481.

Frederick M. Wekesah, Edna N. Mutua and Chimaraoke O. Izugbara (2019)

Gender and conservation agriculture in sub-Saharan Africa: a systematic review, International Journal of Agricultural Sustainability, 17, 78-91.

FAO, 2006. Farm power and mechanization for small farms in sub-Saharan Africa, Rome, 2006

FAO/UNIDO, 2008. Agricultural mechanization in Africa... time for action: Planning investment for enhanced agricultural productivity: Report of an expert group meeting. Rome. Https://www.unido.org/fileadmin/user_media/Publications/Pub_free/agricultural_mechanization_in_Africa.pdf

FARM (2015). An original experience of shared mechanization in Africa: The Farm Machinery Cooperative in Benin, April 2015.

FAO. 2012. Hire services by farmers for farmers. Rome. In particular, pp 1–27 and 43–56. Available at: www.fao.org/3/a-i2475e.pdf

IIRR and ACT. (2005). Conservation Agriculture: A manual for farmers and extension Workers in Africa. International Institute of Rural Re-construction, Nairobi; Africa Conservation Tillage Network, Harare.

Jat, R., Sahrawat, K. L. and Kassam, A. (eds.) (2013). Conservation Agriculture: Global Prospects and Challenges. CABI, Wallingford, CT.

Loch, A., Cummins, J., Zuo, A. and Yargop, R. (2018). Value chain and policy interventions to accelerate adoption of zero tillage in rice-wheat farming systems across the Indo-Gangetic Plains Technical Report · October 2018 ACIAR, Canberra, Australia.

Thiombiano, L. and Meshack, M. (Eds.) (2009). Scaling-up conservation agriculture in Africa: Strategy and approaches. The Food and Agricultura Organization (FAO) Sub-regional Office for Eastern Africa, Addis Ababa.

Recommended websites:

FAO. 2018. Sustainable agricultural mechanization. FAO website. Available at: www.fao.org/sustainable-agricult

9 Conclusions and the Way Forward

Agricultural systems in developing countries are under pressure to increase productivity sustainably and strengthen the resilience of agricultural landscapes. Climate change is likely to threaten the food security and livelihoods of millions of people in South Asia and Africa. In future, the focus will be on CA systems which provide high-quality food with low risks to the environment and public health. Benefits of CA include erosion control, water conservation, improved nutrient cycling and use efficiency, C sequestration, and more stable crop yields. CA principles are universally applicable to all agricultural landscapes and land uses, with locally formulated/adapted practices. CA should be promoted for ensuring food security, restoration of soil health and climate change mitigation, and the key to Sustainable Development Goals (SDGs). The assessment of soil health requires quantification of critical soil attributes (physical, chemical and biological). However, CA is knowledge intensive, equipment and expertise sensitive and requires high cash inputs including herbicides, seed of improved varieties and fertilizers. While significant energy and cost savings have been the basis of wide-scale adoption in mechanized systems, these are not so readily available in West Africa's largely manual/animal-based cropping systems. The most reliable effects of CA (reduced soil loss and increased soil organic matter content), and benefits to farmers' yields mostly observed after 3-5 years. However, farmers need immediate returns to their investments when considering adoption of CA practices, and therefore the long-term benefit is a major hurdle for adoption.

Investment in CA for smallholder farming offers potentially huge future returns by reversing degrading land quality and securing greater return from the investments. CA was first developed through mechanized approaches, and it requires translation into the context of West African farming in ways that do not expect too much from the poor farmer. Some of this translation requires that of the new machinery for drilling into the soil, with crop residues as mulch. Implements used in all the field operations, like hand and oxen-drawn planting and fertilizer drills, would have to be designed and commercialized. The greatest challenge rests in weed management as conservation agriculture relies heavily upon herbicides and smallholders lack the capacity to acquire them and the necessary knowledge and applicators for these operations. The challenge is to distribute relatively expensive CA agriculture machinery to a sufficient number of households to achieve significant impacts on land management, and to break even in terms of project costs and farmer economic benefits.

Developing and promoting CA systems will be highly demanding in terms of the knowledge base. The evidence for the universal applicability of CA principles is now available across a range of ecologies and socio-economic situations covering large and small farm sizes, including resource poor farmers worldwide. However, there are several constraints to adoption of CA in resource poor developing countries. In the seasonally dry tropical and sub-tropical ecologies, particularly with resource poor small farmer in drought prone zones, CA systems will take longer to establish, and step-wise approaches to the introduction of CA practices seem to show promise.

CA adopters in African continent generally retain negligible quantities of crop residues, as surface mulch due to their multiple uses, other than soil amendment, including livestock feed, household fuel, fencing and thatching material, sterilizing material for seed beds, and as a source of cash. More deriving maximum benefits from CA, farmers need to wait for few years after its adoption. Basic principles of CA are not location or cropping system specific but provide the foundation to tailor and integrate needed strategic crop management practices (seeders/implements, crop residue management, cultivars, weed, disease and pest control practices, fertilizer and irrigation management etc.), that must be developed, tested and modified as needed for application to a given crop production system. We recommend adequate investment in 'innovation adoption' with the needed research support, which is lacking.

CA requires adequate and very specific mechanization inputs which could be described as "innovations for sustainable agricultural mechanization". In many developing countries, including West Africa, supportive and guiding policies are required to attract and encourage the agricultural machinery sector to open up and develop markets for agricultural mechanization in general and for CA equipment in particular and to establish the required commercial and service infrastructures. One way to improve the availability of CA equipment for smallholder farmers is to encourage, equip and train local-level entrepreneurs/service providers and custom hiring centres to offer a CA mechanization service in their neighborhood. The custom hiring model enables new machines to be used at their maximum capacity and enables smallholders to gain access to technology they would otherwise not able to afford. The experience from South Asia (especially India and Bangladesh), where small farms dominate, shows that it is possible to improve mechanization through access to smaller and well-adapted machinery. Strong public policies in India have helped create favorable conditions (e.g. credit, insurance, R&D, infrastructure) for mechanization development and uptake. This could also happen in West Africa as well if governments and the private sector work together. Local manufacturing of CA equipment is a desirable goal, as it not only helps to stimulate the local economy, but also provides the opportunity to adapt technologies to local conditions be they crops, soils, climate, production systems, technical knowledge, manufacturing skills or material supply, amongst other factors. However, local manufacturers making an effort to enter into the CA machinery market, may often be at a disadvantage due to their limited knowledge of the details of design parameters for such machinery. The government needs to develop conducive policies and strategies for mechanization. One example would be increased funding for research and training programs, to best adapt the techniques of farm machinery to the needs of family farms. Another could be financial support (subsidies) to the smallholder farming sector, to assist farmers in the purchase of CA equipment, will directly stimulate the local supply chain. The private sector has a role to play in establishing a market for farm equipment and spare parts, and in bridging the gap between demand and supply in various adjacent services. The issues of access to finance, and lack of land tenure security will likely remain in the foreseeable future. Farm size also determines the purchase and usage decision of machinery. How farm sizes will evolve in Africa (consolidation vs. fragmentation) would affect the level of mechanization. Service providers will also often need training in the technical aspects of its correct use, calibration and maintenance, as well as training on the managerial skills of identifying and running a successful service provision model. In many countries such as India, China and Brazil, the rapid expansion in farm machinery demand, has stimulated the growth of local machinery manufacturing. These countries are now major producers and world leaders in farm machinery exports. The same development could happen in Africa, if farmers could intensify their activities through greater mechanization. This would lead to increased input use, higher food production, enhanced food security and reduced dependence on imports. Without this change in the machinery sector, future agriculture development needs of developing countries for food security, poverty alleviation, economic growth and environmental services cannot be achieved. In order to evaluate the profitability of investment in CA machinery it is essential to have information on the costs of acquisition and potential annual usage. Once costs have been calculated and income estimated, then break-even areas, or hours of paid work can be visualized.

The smallholder farmers in both Eastern IGP of India, West Africa, Bangladesh and Nepal find it difficult to justify the investment in CA equipment. Promotion of farm mechanization through CHCs, private entrepreneurs and farmer cooperatives can benefit small and marginal farmers. Cooperatives and service providers provide access to the latest technologies in a relatively short distance in a trustworthy environment without the need of purchasing the machinery themselves. The custom hiring model enables new machines to be used at their maximum capacity and enables farmers to gain access to technology they would otherwise not able to afford. Case studies of Punjab, India show that above' business models can be seen as a mechanism for adoption of CA technologies. Appropriate policy support including incentives and subsidies, particularly for small and medium scale farmers is essential.

Research and development covering a wide range of activities from fundamental scientific research through to practical machine development, and testing is important in the upscaling of CA. Private sector should be encouraged to carry out machine development, as it will have a more focused approach, as well as direct knowledge and understanding of (a) its clientele; and (b) its own capabilities with regard to production technology and costs. Local researchers, engineers and machinery designers need to identify what local demands and knowledge gaps are. Machines should be properly tested and then modified if necessary. The modified machinery will then be introduced to farmers, and tested on-farm so that farmers' feedback can also be used to further improve the machinery. Because research and development are expensive and require skills and expertise, which may not be affordable by service providers, it may be advisable for governments and the private sector to cooperate in order to ensure that activities are closely linked to the identification of markets, and subsequent manufacture. Researchers need to ensure the machines are relevant to local conditions and likely to be of use to farmers. In general, imported machines are cheaper than local machines. It is also important to develop the capacity of local manufacturers. It is likely that their will be a need for separate machines for rainfed and irrigated cropping systems. Several issues responsible for influencing adoption of CA include a lack of availability of the CA machines for small and medium-sized farmers, competition for residues as a source of livestock feed, stubble burning incentives, and a lack of skilled extension manpower for addressing and influencing current tillage mindsets amongst farmers. Developing, improving, standardizing equipment for seeding, fertilizer placement and harvesting ensuring minimum soil disturbance in residue management for different edaphic conditions, will be key to success of CA.

For successful implementation of CA mechanization, consolidation of the widely fragmented and scattered land holdings, extension of benefits of mechanization to all cropping systems, enhancement of the average farm power availability to assure timeliness and quality in field operations and use of precision and efficient equipment to improve the quality of operations is required. Custom Hiring through private entrepreneurs or co-operatives will help to increase annual use of these equipment thereby making them viable. Custom hiring holds an immense potential to change the farm mechanization landscape of India and West Africa.

Their is a lack of knowledge about the potential of CA to agriculture leaders, extension agents and farmers. Capacity development is an essentially process of enhancing the institutional, human and organizational abilities to perform core functions, solve problems and seize opportunities, define and achieve objectives in a sustainable manner. Therefore, capacity building of the researchers, extension officers as well as service providers, is urgently needed who will educate and train the farmers for adopting CA in India and West Africa. Local manufacturers also need training in the production of scale appropriate CA equipment. Adopting CA systems also offers opportunities for crop diversification.

CA practices influence several soil health parameters, reduces soil erosion or increases biological nitrogen fixation by legumes in rotation, exploitation of the deeper soil layers through crops with deep and dense root systems, which have a significant bearing on nutrient management. Unlike in conventional cultivation, application of manures and fertilizer nutrient in the presence of crop residues, as mulch is always a challenging task in CA farming. Evidence shows that in CA systems, nutrient requirements are lower, and nutrient efficiencies are higher. However, systematic research into CA systems and their nutrient management requirements are of relatively recent origin. Various tools, techniques and decision support systems are available to develop site-specific nutrient management plan for each field and dynamically fine-tune in-season nutrient management to increase the nutrient-use efficiency. The improvement in sensor technology and algorithm development needs further research to develop more reliable and suitable models for CA. A wide range of fertilizer products (controlled-release fertilisers, urease and nitrification inhibitors) available in the market which can reduce losses of N and increase NUE need to be evaluated under CA. Increases in NUE under CA should be studied, especially the use of more nutrient efficient genotypes. Breeding programs for developing highly efficient genotypes should be undertaken under CA conditions in different environments. More research is needed on different aspects of nutrient management in CA systems, as more countries begin to adopt and integrate CA concepts and practices into commercial production activities at both small and large scales for future sustainable production. Precise placement of N-fertilizer through side banding in CA system will reduce immobilization (as it separates fertilizer and residue) and volatilization loss. Improved mechanization is needed for fertilizer application at sub surface depth and residue retained condition both for basal application, and at later crop growth stages for split application in different crops including tall crop like maize. Future researches must thrust upon developing cropping system specific nutrient management protocols under CA. Their is a need to develop prescriptions and application strategies in line with the 4R principles to increase nutrient use efficiency taking changes in nutrient dynamics into consideration under CA based management practices. CA has a challenge pertaining to fertilizer application when residues are present on the soil surface as a significant amount of fertilizers is remained on residue and never come in soil contact, if applied through broadcast. Hence the type of fertilizer material (source), rate, time and method of application have to be evaluated in CA properly to increase the crop productivity, input-use efficiencies, farm profits and restore the nutrient supplying capacity and soil health. Their is a need to develop complete package of practices (fertilizer, irrigation, weed control, pest management, etc.) for CA based cropping systems for each agro-ecological region. The genotypes developed under conventional agricultural practices may not be suited to CA, which has drastically different soil environment. Despite the published studies on breeding for nutrient efficiency, the release of new crop cultivars with improved nutrient efficiency is limited, particularly under CA. Biotechnology offers the opportunity to improve nutrient efficiency in crop plants by transferring the identified genes into other species or using them as molecular markers in breeding programs for CA. The genotype x environment x management interactions have now been well documented in CA.

Managing agricultural water to enhance crop WP (more crops per drop) without detrimental effect on resource base is of paramount importance for both rainfed and irrigated agriculture. CA offers an integrated approach for conserving water resource which is a most vital for agricultural production system. Capacity building on micro-irrigation technologies (drip and sprinkler irrigation) for getting technical support in operation and maintenance of such systems. More research is needed to develop irrigation water scheduling to different crops under CA to reduce irrigation water requirement. Use of ridge and bed planting of crops like maize, wheat, groundnut, cotton, and sugarcane crops is recommended to minimize water use.

The objectives of integrated weed and pest management under CA are the same as for conventional agriculture: sustain productivity, conserve natural resources, reduce production costs, improve environmental health, maintain biodiversity, and reduce agrochemical use for crop production/protection. The CA-based crop management techniques may face the major concern of weed management initially. Therefore, proper weed management is considered one of the most important prerequisites in CA-based crop cultivation systems to ensure high crop yields. Hence, judicious weed management in CA system is a critical factor for securing and sustaining food security. Weed species shifts and losses in crop yield as a result of increased weed density have been cited as the major hurdles to the widespread adoption of CA. Weed control, although a major challenge in the initial years of conversion to CA, can be managed by a suite of options in reach of smallholder farmers. The reported adverse weed changes have been assigned to partial adoption of CA by smallholder farmers and argue that under recommended CA practices weed pressure and related management begin to decline from the third year of CA adoption. Without effective weed management and control strategies, successful adoption of CA in smallholder farming systems in most countries of Africa is rather unlikely. This is because maximum benefits are obtained when the three pillars of CA - minimum tillage, permanent soil cover and crop rotation - are applied simultaneously and in conjunction with good agronomic management including weeds. To address the weed management problems in CA-based production systems, chemical weed control is a potential means for controlling weeds, and more economical compared to hand weeding. Policy makers and service providers may consider an enabling environment for improved access to the various options available for weed control. As an important pre-requisite, extension agents must be trained in herbicide use, and it's application in order to show farmers how to optimize input use and limit and control the potential negative impacts of herbicides use on the environment and human health by using applicators and protective clothing. The integrated pest management requires knowledge of crop-susceptible stages, and the nature of insect pests, as well as increased monitoring. Their is no evidence of complete control of insect pests in CA farming systems, which remains a challenge for researchers, farmers, and agriculture policy makers.

CA practices in relation to the specific management regimes have shown noteworthy improvement in soil physical, chemical, biological properties, and conserving soil moisture. Besides promoting carbon sequestration and enhancing natural resource base, CA in long run compliments the environmental protection by reducing the GHGs emissions. A focused research/development strategy along with the production protocols, however, is needed for soil health restoration, and realization of the potential benefits of CA. In contrast to rainfed low rainfall areas, in irrigated systems, the application of irrigation water appears to 'hide or postpone' the expression of the degradation of many soil properties until they reach a level, that no longer can sustain high yields, even with irrigation. Consequently, assessments of soil properties and recommended management actions will likely need to be site-specific, bearing in mind that the plasticity of the supply of functions and the demand for them, differ from one place to another. Establishment of long-term experiments or research platforms at different sites and soil types will provide useful database for simulation modelling. Appropriate fertilizer and irrigation management strategies for CA systems should be developed, so that soil health is maintained or improved. Development of CA based best bet management, efficient input and resource management with multiple stresses tolerant varieties can help in mitigating the adverse impact of climate change and variability. CA is built on system perspective working in partnership with farmers. Researchers, extension agents and farmers need to work together in partnership to adjust the CA system to local circumstances also involve other players as necessary, such as machinery manufacturers and other private sector stakeholders.

The CA approach for managing agro-ecosystems is of paramount significance in improving soil health, sustained productivity and maintaining natural biodiversity. CA practices in relation to the specific management regimes have shown noteworthy improvement in soil physico-chemical properties viz., soil aggregation, density, penetration, thermo-regulation, water and nutrient interaction for maintaining a favourable soil-water-plant continuum. CA practices had a positive impact on soil organic C–pools, macro–aggregate formation, and carbon stock in aggregates. The CA systems could maintain higher passive C–pool over CT and thus upgrade the quality of organic carbon, which persist longer in the soil.

A focused research/development strategy along with the production protocols, however, is needed for soil health restoration and realization of the potential benefits of CA. Soil health has no constant and ubiquitously applicable value for the function of nutrient cycling and even less so in view of other soil functions. Lower potential production due to soil degradation may not show up in intensive, high-input systems, until yields are approaching their ceiling. Consequently, assessments of soil properties and recommended management actions will likely need to be site-specific, bearing in mind that the plasticity of the supply of functions and the demand for them, differ from one place to another. Many changes in soil quality become apparent after few years (5 yrs or more). The assessment of soil health requires quantification of critical soil attributes (e.g. physical, chemical and biological). CA should form an important component of our national strategy to produce more food sustainably at less costs, improve environmental quality and preserve natural resources. Scientific research is generally carried out in universities or in government research institutions. Collaboration of BISA/CIMMYT with these organizations in India & West Africa will help strengthen graduate students' research and young scientists training in CA. There is a need for regional and South - South cooperation to bring mechanization at larger scale like knowledge, experiences and expertise sharing/exchange programmes, research and partnerships, capacity building by study tours, manufacturers training and students' exchange programs etc..

There is a limited information on interactions between CA and gender issues in South Asian and West African countries. There is need for the programmes in CA to have a clear gender policy and implementation strategies that will ensure mainstreaming of gender from planning point to farming households, to enhance equal participation of women and men. Future research should focus on gender and CA should include: serious focus on and understanding of gender as a social construct in relation to CA; the long-term impacts on CA for gender relations, incomes for men and women, and women's empowerment; and the sustainability of strategies for supporting gendered participation in CA.

About BISA

The Borlaug Institute for South Asia (BISA) (www.bisa.org) is a non-profit research institute through a collaborative effort between the ICAR, Government of India and CIMMYT to serve as a regional platform with a mission of "Food, Nutrition, Livelihood and Environmental Security in South Asia".

About CIMMYT

The International Maize and Wheat Improvement Center, known by its Spanish acronym, CIMMYT (www.cimmyt.org), is one of the 15 CGIAR centers and a not- for-profit research and training organization with partners in over 100 countries. CIMMYT works with a mission of "Wheat and Maize Science for Improved Livelihoods."

CIMMYT-India
CG Block, NASC Complex, DPS Marg Pusa
New Delhi-110012, India.
Ph: +91 (11) 65441938; + 91 (11) 65441940; + 91 (11) 2584 2940
Fax: +91 (11) 2584 2938